Black Holes in Orbit

Summary

Students are introduced to the basic properties and behavior of black holes through a brief discussion, including how it might be possible to detect black holes through their interaction with other stars. Then they "act out" binary star systems in pairs, walking slowly around one another in a darkened room with each pair holding loops of wire to simulate the gravitational interaction. Most of the students play the part of stars and are wearing glow stick necklaces to symbolize this. The students who are not wearing necklaces play the part of black holes. A small set of the black holes have flashlights, which represent X-ray emissions.

Purpose

To teach some of the properties of black holes and how they interact with normal stars.

Audience

Approximately 20 students (grade range 6^{th}-9^{th}) in a group works well

Objectives

- To learn the basic properties of black holes, including:
  - Escape velocity
  - Gravitational interactions
  - Accretion disks
- To consider black holes less mystifying
- To brainstorm ways to observe objects or phenomena which cannot be seen directly
- To be introduced to basic X-ray physics

Badge Requirements

Materials

- 1 tennis ball
- 5-6 loops of heavy gauge wire, ~ 36 inches in circumference
- 5-6 loops of heavy gauge wire, ~ 60 inches in circumference
- glow stick necklaces
- 6 flashlights and batteries
- red cellophane to cover flashlight lenses
- tissue paper party decorations – 2 large (~ 8 inch diameter) balls, 1 large (~ 24 inch diameter) disk
- room with adequate space to move around for the activity
- Dark room

Preparation

1. Wire loops: approximately 10 minutes
   Cut and shape the wire into 5-6 medium sized loops (approximately 36 inches in circumference) and 5-6 large loops (approximately 60 inches in circumference). Make a figure 8 shape with both loop sizes, attaching two of the same size together. The students will use this to simulate the gravitational pull at different distances between stars and black holes.

2. Flashlights: approximately 5 minutes
   Cover the lenses of the flashlights with cellophane or tissue paper, and tape this into place.

3. Darken the room: variable
   The room should be capable of going from brightly lit to dark so that the glow stick necklaces can be seen effectively. Sometimes this means lights or light leaks must be covered. Dark black plastic trash bags and duct tape have proved useful for this.

Activity

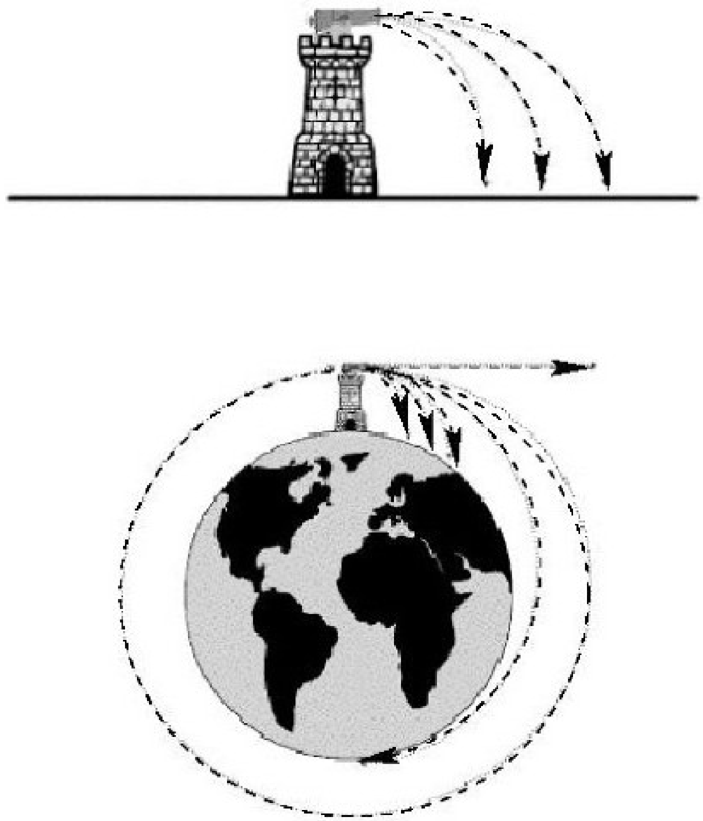
This activity can be completed in 45 minutes. A sample script and flow of discussion follows.

I. Discussion: What is a Black Hole? *(approximately 15 minutes)*

1. **The concept of an orbit:**
   If an object orbits another object, it goes around that object in a fairly fixed circle or oval. The Moon orbits the Earth. Earth and the other planets orbit the Sun. Sometimes two stars orbit each other. When this happens, we call them binary stars. Roughly half of the stars visible in the sky are binary stars, so this is relatively common. You can demonstrate the idea of an orbit using the two round party decorations (or any other round objects).

2. **Escape velocity:**
   Use the example of a tennis ball to help explain this concept. If you toss a tennis ball in the air, it falls back down to the ground. If you toss it a little bit harder and faster, it takes a bit longer to fall back down to the ground. Theoretically, if you could toss this tennis ball hard enough and fast enough, it would not fall back down. The illustration below of a cannonball being shot from a tower also illustrates this idea. As the cannonball is shot with more speed and force, it goes farther and farther. Eventually, with enough speed and force, the cannonball goes into orbit. With even more force than that, the cannonball escapes entirely. The minimum speed that anything must be going in order to escape an object's pull is known as the escape velocity, and it varies depending on the mass of the object. The speed you would have to throw the tennis ball on the Moon is less than the speed you would have to throw it on the Earth because the Moon is smaller and less massive than the Earth. Likewise, the escape velocity for the Sun is much greater than the escape velocity for the Earth because the Sun is much more massive than Earth.

Escaping Gravity



Source: http://www.adlerplanetarium.org

3. **What is a BH?**
   A BH is an object so massive that the escape velocity is greater than the speed of light. This means that nothing, not even light, which is the fastest thing in the universe, can ever escape from inside a BH. The fact that no light can escape from these objects is why we call them *black* holes.

4. **How would you observe a BH?**
   If not even light can escape a BH, then how can we know they're there? After all, space looks black as well. The primary way that we observe BHs is by the effects of gravity. If a star in a binary star system becomes a black hole, it will still have another star orbiting around it. When we observe such a star apparently orbiting around nothing that can be seen, we can assume that there is a BH there. We will be doing an activity to demonstrate this idea.

5. **What is an accretion disk?**
   Though BHs are not cosmic vacuum cleaners that wander around the universe sucking

things up, their gravitational pull does cause nearby material to be pulled in. This effect is most pronounced when the BH is orbited by another star. As material spirals in towards the BH, a disk is formed. [You can use the tissue paper disk and ball to illustrate an accretion disk and an orbiting star.] The materials in this disk interact with each other, and as they do, friction causes them to become very, very hot. This causes light to be emitted, usually in the form of x-rays. Since this light is generated by material around the BH, not actually in the BH, this light can escape, and we can detect it, giving us another way of detecting a BH. At the end of this session there is an image of an artist's conception of an accreting black hole that can help with student visualization of an accretion disk.

II. Kinesthetic Activity *(approximately 20 minutes)*

In this activity, students will play the part of stars and black holes, and observe how astronomers might be able to detect these objects, even though no light escapes from them. The numbers below assume a group of 25. You should adjust the numbers accordingly for the size of group and the space that you have.

It might be worthwhile to have some of the students on the sidelines as observers, and then have them switch with the participants, to give everybody a chance to both observe and act out a role. It is also useful to have a helper stationed by the light switch who can make the room go dark at will.

1. Demonstrate an orbit for the purposes of this activity by having two volunteers hold onto opposite ends of a figure-eight wire, pull it apart, and circle around each other.

2. Have 16 of the students wear glow stick necklaces. These students are "stars." The rest of the students will not wear the necklaces, and will therefore be invisible in the dark; they will be the "black holes."

3. Divide the students up roughly as follows:

   3 of the students will be normal stars, without a pair, moving through the galaxy. 5 pairs of students will be normal binary star pairs orbiting around each other. 5 of the students with necklaces will pair with 5 students without necklaces to be normal star & BH binaries. The remaining 2 students without necklaces will be BHs without a pair.

4. Each pair (whether a pair of normal stars, or a star and BH pair) should be given a figure-eight wire. These wires come in different sizes to represent differences in how closely objects orbit each other. Any BHs who are paired with a star using the smaller sized figure-eight wire should be given a flashlight. One of the unpaired BHs should also be given a flashlight.

5. Explain that the lights will be turned off and each pair of students will orbit each other. The unpaired students will move slowly around the room on their own. Make sure you tell all the students to circle or move slowly so as to avoid injuries. Tell them that the flashlights should stay off until a signal is given. Practice the activity once with the lights on.

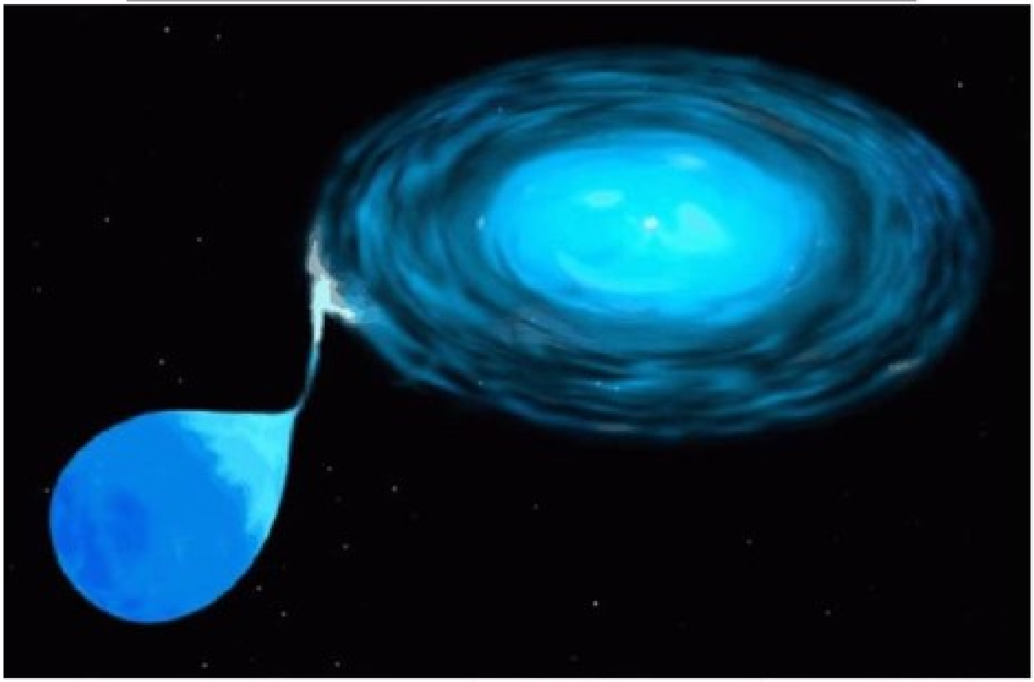
6. Turn the lights off and run through the activity. Have the students observe what happens. They will be able to see the 'stars' because the glow stick necklaces give off light. The 'BHs,' however, will be invisible (this is most dramatic when you can fully darken the room). Whenever a BH is paired with a normal star, they will be able to see the star going around something, but they will not be able to see what. This is what happens with BHs in space.

7. When you are ready, give a signal, such as saying "Turn on your x-ray detectors." At this signal, those students with flashlights should turn them on. Everybody should now be able to detect the x-rays emitted by the accretion disks around some BHs. The idea here is that with the closer binary systems, the star and BH are close enough for accretion to take place, i.e. the star "donates" some of its mass to the BH, and X-rays are emitted. This demonstrates a second way that scientists can detect BHs.

III. Wrap-up *(approximately 10 minutes)*

Ask them questions based on this activity. Probe whether they now understand what a BH is and how we detect them. While the leader does this, the helpers should go around and collect the flashlights and wire loops used in the activity.

An Accreting Black Hole



Credit: Astronomy Picture of the Day
http://antwrp.gsfc.nasa.gov/apod