Name ______________________ Class ______________ Date ______________

Curving Space-Time

One of the essential ideas behind modern astrophysics and cosmology is the theory of general relativity. One of the aspects of this theory is that space and time are treated as equivalent dimensions, so that a complete treatment of space and time involves a four-dimensional "space-time." This can be visualized more easily with a three-dimensional model, in which space is flat (two-dimensional) and time is the third dimension. When you model the expanding universe with an inflated balloon or ball, the surface of the balloon depicts space, and the changing radius of the balloon represents time.

Another important aspect of general relativity is that gravity is no longer treated as a force that acts on objects at a distance. Rather, gravity is treated as a force that deforms the space-time around a body. Because space-time is bent, an object that passes near the body is deflected by the curved space-time in the same way that it would be deflected by gravity in a traditional three-dimensional model. An important feature of the general relativity model is that anything that moves through space-time, even light, is affected by gravity. The classic model of gravity did not predict such a deflection, yet the deflection of light passing near stars and galaxies has been observed, thus verifying the relativistic model. In this lab, you will model the space-time around a star and note how the path of a passing object varies with the mass of the star, and thus the distortion of space-time.

OBJECTIVES

Test how changes in mass affect the curvature of space-time.

Model how much the path of an object or light is affected by a large mass.

Measure how much the path of matter or light is bent by increasing mass.

Demonstrate the relativistic interpretation of gravity.

MATERIALS

- cardboard or wooden box, about 30 cm × 30 cm × 30 cm
- markers, non-toxic, 4 colors
- mass, 100 g
- mass, 200 g
- mass, 500 g
- meterstick, flexible
- permanent marker, black, non-toxic recommended
- protractor
- stapler and staples, or thumbtacks
- tape, clear, 2 in. wide (optional)
- white swimsuit fabric, about 31 cm × 31 cm

SAFETY 

ASK A QUESTION

1. How does mass affect the curvature of space-time, and how does that curvature affect the path of an object moving near the mass?

FORM A HYPOTHESIS

2. Form a hypothesis that answers your question. Explain your reasoning.

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TEST THE HYPOTHESIS

3. Spread the swimsuit fabric on a desk, table, or some other smooth, flat surface. It may help to hold the fabric in place if you tape the edges down. Use a permanent marker to mark a grid with vertical lines that are 5 cm apart, and horizontal lines that are also 5 cm apart.
4. Cover the open top of a box with the swimsuit fabric. Stretch the fabric across the opening so that it is tight but could still stretch much farther. Use thumbtacks or staples to secure the fabric around the rim of the box top. The marked fabric is a two-dimensional model of space. **CAUTION:** Be careful not to cut or puncture skin with tacks or staples.
5. Use one of the colored markers and the ruler to mark a straight path from the middle of one side of the box to the middle of the opposite side. Draw the path by making small, 1 cm-long marks end-to-end. Press the marker lightly, being careful not to stretch the fabric while marking the path.
6. Place the 100 g mass in the center of the fabric. You may observe that the grid lines drawn on the fabric are slightly distorted and stretched by the mass. Repeat step 5 using one of the other colored markers. This represents the path of an object deflected by curving space-time. Place this line as near to the first line as possible, making sure that the line is straight and initially parallel to the first line. Again, try not to stretch the fabric much while making the marks. Use the ruler to be sure that the marks are made end-to-end, especially in the area of the depression made by the mass. Does the second line eventually cross the first line?

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7. Repeat step 6 using a 200 g mass and the third colored marker. Record your observations about how the third line differs from the first two lines.

8. Repeat step 6 using a 500 g mass and the fourth colored marker. Record your observations about how the fourth line differs from the other lines.

9. Remove the mass and detach the fabric from the box. Use the protractor to measure the amount each line is deflected from the initial straight path.

ANALYZE THE RESULTS

1. **Making Comparisons** Which mass caused the greatest distortion in the fabric? Which mass produced the line with the greatest deflection?

DRAW CONCLUSIONS

2. **Evaluating Methods** What are some of the sources of error and uncertainty in this experiment? Explain your answer.

3. **Drawing Conclusions** From your observations what can you conclude about the effect mass has on space-time, and how this effect alters the path of matter or light? How is this similar to the effect of gravity on objects passing more massive objects?

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EXTENSION

1. **Research and Communication** Research the experimental evidence for the general relativity model of gravity, and summarize your findings below.

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