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Spacetime Simulator

(Adaptation of original design by Daniel Burns – Physics Teacher at Los Gatos High School in California)

Materials:

2 – ¾ in. x 10 ft. PVC Schedule 40 Plain-End Pipe – White (Home Depot Model# 57471)
4 – ½ in. x 10 ft. PVC Schedule 40 Conduit – Grey (Home Depot Model# 67447)
20 – ¾ in. Schedule 40 PVC Tee (Home Depot Model# C401-007)
20 – 2 in. Spring Clamp (Home Depot Model# 80002)
2 yds – Dance/Swim Knit Solid Fabric (JoAnn Item #7161417)
1 – Rubber Doormat (Available at Walmart for a couple dollars)
2 – Rocks with flat surfaces (pick these up out in the wild somewhere)
100s – Marbles (Look for them at dollar stores)
1 – 2-Wheeled Duffel – 30" width (optional but super useful for transporting simulator)

Tools:

Ruler or Tape Measure
Sharpie or other writing material
PVC Cutter*
Kitchen Shears

*If a PVC Cutter is not available, other tools like a chop saw can be used to cut the PVC pipe – be careful!

Spacetime Simulator Construction:

1) Using the sharpie and tape measure, mark each white ¾" PVC pipe every 2 feet.
2) Using the PVC cutter (or other tool), cut the PVC pipes at the 2-foot marks you made. This should result in TEN 2-foot-long pieces of white PVC – now called struts.
3) Press fit a ¾" PVC tee connector to each end of the struts. Be sure the tees are lined up parallel to each other. (Image below - left)
4) Cut the rubber doormat into 2.5" x 5" rectangles. These measurements are approximate. These pieces will be used between the clamps and the fabric to protect the fabric from getting holes. (Image below – right)

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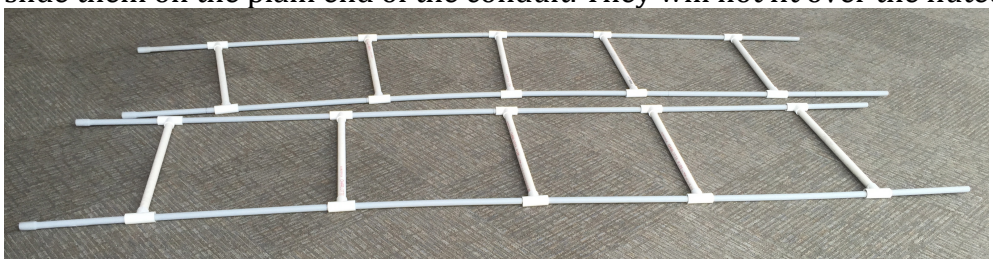
Spacetime Simulator Assembly:

1) Lay the 10' long sections of PVC conduit out on the ground parallel to each other (with the fluted ends on the same side) in pairs about two feet apart.
2) Slide 5 of the struts onto each pair PVC conduit as shown in the image below. You must slide them on the plain end of the conduit. They will not fit over the fluted end.



3) Connect the plain ends of one set of conduit to the fluted end of the others so you have what looks like one big ladder.
4) With assistance, bend the conduit ends to meet each other. You will need someone to stand opposite you at the connection so you can push the ring into and oval. This will allow you to press fit the plain end of the top and bottom conduit rings into each other.
5) During assembly, the struts will likely slide together. Space them out evenly along the conduit. The frame when assembled should look like the image below.

6) Time to stretch and secure the fabric of spacetime. Start along the 58" width in the middle. Using the cut rubber doormat rectangles, secure the fabric on either side of each strut as shown in the image below. Keep the fabric as loose as you can along the 58" width and then match the tension along the 72" length as best you can. It works best if you secure one side, then move to the opposite side. From there move 90 degrees to the middle of the other dimension and then the opposite side of that. Then, secure the fabric around the other struts as shown in the image below.

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7) Simulate away! You can see ideas for demonstrations in this original video from Daniel Burns: http://bit.ly/spacetime_sim We use rocks instead of the slotted masses which can be quite expensive.

Hints and Tips:
Short Science Story (S^3) – Albert Einstein imagined masses (like the Sun, Earth, and Moon) warping spacetime. The larger the mass, the more it warped the spacetime around it. In this spacetime simulation, the rocks warp the fabric of spacetime in the same way Einstein described. You can model many of the observed phenomena we know about including the figure eight flight path the Apollo missions took to get to the Moon and back again to Earth as well as the reason why we have just a few planets all moving around the Sun in the same direction.

Many students ask what a black hole would look like on the simulator. If you had an infinitely deep well (or stepped right in the middle of the simulator and stood on one leg – ONLY imagine this, don't do it), that would represent a black hole.

At large outreach events, we usually just have the two rocks representing the Earth Moon system on the spacetime fabric. When then give participants five marbles at a time, which they can put on an orbit to see if they can model the figure eight pattern taken by the Apollo missions to get from the Earth to the Moon and back again. Our record is three figure eights from one trial. It is nice to have large quantities of marbles so you don't have to collect them as frequently.

Having two different sized rocks is nice so you can ask which represents the Earth and which represents the Moon. They do not have to be to scale.

After a hundred or more trials, you can usually have students observe that the Earth has more marbles around it than the Moon. This is due to its greater mass and therefore bigger gravity well created when it is sitting on the spacetime fabric.

The Sun with marbles released in either direction showing near the end a few satellites all moving in the same direction (like our solar system) is also a favorite demonstration.

The other demos from Mr. Burns' video are best left for a more advanced physics demonstration with lecture. In fact, if you want to go way above and beyond, you can even simulate gravity waves like those recently verified at LIGO. You will likely need a smaller simulator as reaching the center of this one is a bit tough. Hula hoops make great small simulators. See this video for details: http://bit.ly/grav_waves