**General Relativity for grade-9 Astronomy (and grade 12 Physics) OAPT Conference 2011**

1. **Orbits**
2. **Why doesn’t the moon fall down**? Have your students discuss this before showing them the one-minute animation. Newton’s great insight was to recognize that the force that made apples fall, was also the force that made the moon and planets orbit.

[www.perimeterinstitute.ca/Outreach/Alice\_and\_Bob\_in\_Wonderland/Alice\_and\_Bob\_in\_Wonderland/](http://www.perimeterinstitute.ca/Outreach/Alice_and_Bob_in_Wonderland/Alice_and_Bob_in_Wonderland/)

1. **How can gravity make things fall and orbit without touching them**? Your students have probably never wondered why things fall down - they are so use to it. Gravity makes things fall down. But how can the Earth pull without contact? And how does the Earth pull on the Moon across such huge distances? This really bothered Newton. Newton couldn’t answer this question and he didn’t think that it could be answered be made. Later on, physicists developed the concept of fields. This was applied very successfully by Maxwell to electric and magnetic fields. He predicted that these fields could exist and move independently of any charges. He predicted electromagnetic radiation – light, x-rays, radio waves etc. However, gravitational fields didn’t seem to have any independent reality like this and they also had the strange property of giving all masses the same acceleration. Einstein’s general relativity proposes that the gravitational field is a warping of spacetime. Mass tells spacetime how to curve and the curve tells other masses how to move.
2. **Why can’t we see this curved space?** We are dealing with three dimensions warping into a fourth – something that is impossible to visualize. To begin understanding why we can’t see this, watch this 5-minute video where Dr. Quantum tries to convince a 2-D creature that there are three dimensions. [tp://www.youtube.com/watch?v=BWyTxCsIXE4](http://www.youtube.com/watch?v=BWyTxCsIXE4)
3. **Aren’t all analogies and physical models of warped spacetime wrong?** <http://xkcd.com/895/> Well, yes, but that shouldn’t stop us. It helps to gain a hint of what is happening.
4. **How would an ant on the spacetime fabric explain the orbits?** An ant on the fabric only knows about two dimensions - left/right and forward/backward. It has no concept of up/down. It will probably come up with a law of gravity that has masses attracting each other without contact. Note: This activity allows students to explore orbital motion, even if you never mention general relativity. They can discover that the closer the orbit is, the faster the ‘planet’ moves. The bigger the central mass (deeper the well), the faster it orbits and that the mass of the planets has little effect.
5. **Why aren’t we spiralling into the sun?** In our model, the planets eventually spiral in because of friction and so you want to use fairly dense balls to reduce this effect. Therefore, use a rubber ball, not a ping pong ball. They also lose energy to ripples in the fabric. This is less noticeable if you use light balls. Therefore, use a small marble rather than a billiard ball. It is also less noticeable if you use really thick stretchy fabric. This will cost $20 rather than $10. However, no matter what you choose, the balls will spiral in. Shouldn’t the ripples in spacetime also make orbits spiral in? They do! This has been measured to unprecedented accuracy in a binary pulsar system by Taylor and Hulse who received the Nobel Prize in 1993 for this work. This is the only evidence - so far - for gravitational waves. They were able to detect the effect because pulsars are extremely dense neutron stars that emit a strong radio signal. The density means that the spacetime is extremely warped and so the effects are more pronounced. The strong radio signal allowed them to detect the two stars.
6. **Why aren’t we spiralling into the Sun?** We are but the effect is too small to measure. Pulsars are extremely dense neutron stars orbiting really fast. They make ripples big enough to detect. (The fact that they are pulsars emitting a strong radio beacon makes them easier to detect.)
7. **How does an orbit in Newton’s flat space differ from one in Einstein’s curved space?** This can be demonstrated by tracing a cardboard ellipse on a balloon. Blow the balloon fully so it is firm and doesn’t flatten when the students draw on it. Make the cardboard shape similar in size to the balloon so it experiences the full curve of the balloon and not just a small flat-like part. An elliptical orbit shifts its orientation with each orbit. This is called the precession of the perihelion. Orbits can precess for other reasons like the tug of the other planets - especially Jupiter. In 1859 it was noticed that after the known Newtonian effects were removed, Mercury still had a significant precession. They thought it was evidence of another planet near the Sun, which they named Vulcan. However, Vulcan didn’t exist. Einstein’s equations were able account for this. This was general relativity’s first success.
8. **Why hasn’t the precession been seen for the other planets?** The relativistic precessions for Venus and Earth have been measured. However, the effect for the other planets is too small to be measured as yet because they are farther from the Sun where the warping is less significant.
9. **Light**
10. **What effect will the sun have on starlight?** If the tape is applied smoothly over the bowl, its path will change and bend toward the sun. (Note: If the bowl was right side up and formed a trough rather than a hill in the space, the path would still bend toward the sun. In this model, there is no use of gravity and so there is no distinction between up and down. It is perhaps a better model than the fabric for this reason. The fabric basically used gravity to explain gravity. You can use the spacetime fabric demonstrate a repulsive field as you get in Rutherford’s alpha particle scattering. Clamp the fabric to a table using a couple of boards and stick something underneath to form a hill.) If the path is bent, the object’s position appears to be shifted way from the sun. When this was tested in 1919 Einstein became a huge celebrity. Perhaps it was because the First World War had just ended and they wanted a good news story. Einstein was a German pacifist and the expeditions were organized by Eddington, an English pacifist.
11. **Why was the test done during an eclipse?** To see the effect, the starlight must pass very near the sun. Therefore, to see the star we need to look toward the sun which means we are looking at stars during the day! Only during an eclipse, will the sun be sufficiently dim to let us see the stars. This same effect is now measured much more accurately during the day without an eclipse using quasars. This is because quasars are very bright in radio waves and the Sun is not.
12. **What different shapes can you see?** To see the effect clearly you want a wine glass with a smoothly increasing thickness in the base and a circle with a diameter similar to that of the stem. You are only interested in the effect of the base, so it you wanted to, you could cut off the glass and stem. You should be able to see warped circles, double warped images and - if centered perfectly - you will see a ring. Einstein predicted gravitational lensing, but didn’t think we would ever be able to see it. It is also used to confirm the existence of Dark Matter. You can get a free 30-minute video from the Perimeter Institute, with teachers guide that will let your students understand how orbital motion and gravitational lending have led to a realization that 80% of the matter in the universe is a new kind of matter, for which we still don’t have an explanation. <http://www.perimeterinstitute.ca/Perimeter_Explorations/The_Mystery_of_Dark_Matter/The_Mystery_of_Dark_Matter/>
13. **Black Holes**
14. **How can black holes be detected and measured if light can’t escape**? Students may think that black holes ‘suck’ all nearby objects and light into them. They don’t. The warp space like any other mass, but if the objects have enough sideways velocity, they can orbit. Even light will orbit! Astronomers can measure the orbital speeds and radii and calculate the mass within. This animation shows real data it is not a simulation. Note, that the times are being measured in years. This animation is seriously sped up! The animation can be found at <http://www.einstein-online.info/spotlights/milkyway_bh>

The supermassive black hole in the centre of our Milky Way galaxy is the strongest candidate for a black hole. It has a mass of 4 billion suns within a radius similar to our solar system. This not proof but it is hard to imagine what else it could be. In the next few years, it is expected that we will have enough resolutions to see the event horizon. This is a mathematical ‘edge’ to the black hole. Anything within that radius cannot escape and so we can have no idea of what is happening in there. You can calculate the radius of the event horizon – the Schwartzchild radius using Newtonian physics and get the right answer if the black hole is not spinning. You can also calculate the radius at which light will orbit. However, the answer you get is inside the event horizon. The answer from general relativity is three times bigger and 1.5 times the Schwartzchild radius.

1. **How can gravitational lensing be used as a tool by astronomers?** It can help detect invisible objects like dark matter and black holes. It can also act as a glass lens and help detect faint distant objects.
2. **What will a black hole look like from the other side?** A hole in a box looks like a hole from one direction only. It looks black even if you shine a flashlight at it. However, a black hole looks like a hole from all directions. This is part of the strangeness that comes from warping into a fourth dimension.
3. **What will the Earth look like if it were orbiting a black hole?** In this simulation, the Earth appears to get warped and change colour, but it isn’t actually changing. The changing colour is due to the Doppler Effect which is how astronomers usually measure speed. Given the amount of distortion in this simulation, the Earth should actually be affected and torn apart by tidal forces. The tidal effects occur because the part nearest the black hole is pulled harder than the part farther away. Going near a black hole will spaghettify you. <http://jila.colorado.edu/~ajsh/insidebh/lensearth_640x480.gif>
4. **Can we travel through time?** This is 1-minute animation shows how black holes can be used to travel through time. It also shows what you would see looking away from a black hole. The universe will be really bright and sped up in time. It will also be blue-shifted. <http://www.perimeterinstitute.ca/en/Outreach/Alice_and_Bob_in_Wonderland/Alice_and_Bob_in_Wonderland/>
5. **Why doesn’t time travel slower on the Earth?** It does, but the effect is really small. However, it is big enough that the GPS must account for it or the errors would amount to 14 km each day. There is a free resource form the Perimeter Institute that explores this with a 5-minute video and a teacher’s guide. [http://www.perimeterinstitute.ca/en/Perimeter\_Inspirations/General/Perimeter\_Inspirations](http://www.perimeterinstitute.ca/en/Perimeter_Inspirations/General/Perimeter_Inspirations/)
6. **The Big Bang**
7. **How do we know the universe started in a big bang?** The galaxies are moving away from us as measured by their Doppler red-shift. The farther ones are moving faster than the near ones. If you run the motion backwards, it looks like everything was in one place at the same time 13.8 billion years ago.
8. **Why is everything moving away from us?** Do we have galactic body odour? This model uses paper clips to represent the galaxies because they look a bit like spiral galaxies and will not stretch. The galaxies are held together by gravity and only the space between them stretches. With this model, the students can see that all the galaxies are moving away from all the galaxies – we are not special. They can take data to show that the farther galaxies move more than the nearby ones.
9. **Why does the expansion of space cause cooling?** Blowing with an open mouth vs. a pursed mouth shows how the expansion of the air from a pursed mouth results in cooling, but it doesn’t explain why this happens. The slinky does. As it is stretched, the wavelength of the Slinky increases just as light does while the universe expands. Longer wavelength radiation is lower energy radiation. This is the same relationship that lets us know the temperatures of the stars. The blue stars are hotter than the yellow stars (like out sun) which are in turn hotter than the red stars.

You can get the PowerPoint slides and an electronic copy of this worksheet on my website at <http://roberta.tevlin.ca> . Please feel free to email me with comments, questions and suggestions at [roberta@tevlin.ca](mailto:roberta@tevlin.ca).

I will be teaming up with Dave Doucette again this year to present the three-day almost free ($50 covers all accommodation and supplies!) Physics Camp sponsored by the OTF. It is going to take place on the beautiful campus of Laurentian University (star gazing and lake swimming is available) form August 10th to 12th. Come and join us! It will be lots of fun and even useful!

For more information on general relativity I recommend:

1. **Einstein Online** - <http://www.einstein-online.info/>
2. **Einsteins' Mirror** - by Tony Hey and Patrick Walters 1997
3. **Was Einstein Right?** - by Clifford M. Will 1993
4. **Black Holes and Time Warps: Einstein's Outrageous Legacy** - by Kip Thorne 1994
5. **Physics for the 21st Century**: Unit 3 Gravity <http://www.learner.org/courses/physics/unit/text.html?unit=3&secNum=0>