**News from the Cosmic Microwave Background TAPT Feb. 2014**

In March 2103 the map of the Planck Satellite survey of the Cosmic Microwave Background was released. It is the oldest picture of the universe. It looks like a random bunch of speckles, but it provides a lot of very precise information about the universe; what it is made of, how it evolved and what its future will be like.

**Part 1: What is the Cosmic Microwave Background?**

1. The galaxies appear to be moving away from us. The farther they are – the faster they are receding. This suggests that the universe was once much

A) smaller B) denser C) brighter D) all three  
How can you illustrate your answer using bubble gum, sponges and flashlights?

1. Blow on your hand using a wide, open mouth. Blow on your hand with a small, pursed mouth. This suggests that the early universe was much
2. hotter B) colder Explain using the blowing activity.
3. A higher temperature means that particles in the universe are moving faster and colliding more frequently and with more energy. This suggests that the universe used to be more
4. uniform B) uneven

Explain by referring to what happens if you stir a mixture of oil, vinegar and spices or heat ice water.

1. What is true about the Big Bang theory?
2. It is a very successful television show
3. It used evidence for an expanding universe to infer that it used to be very small, dense, hot and uniform.
4. It successfully predicted a number of other features including the cosmic microwave background.
5. all of the above
6. According to the Big Bang theory, the universe used to be a hot soup of electrons, protons, neutrons and light. Once the universe had ‘cooled’ to 3,000 K, electrons would be able to join with protons to form hydrogen. Now that the electrons are bound up with protons, the light is able to pass by without being scattered off free electrons; the universe became transparent. How can you model this change in a ‘dance’?
7. The light that was around when electrons and protons combined has been travelling for a long time and during this trip the light will have become
8. redder B) bluer C) stretched D) squished

Explain:

1. The original wavelength of the light was 1 m or one millionth of a metre. The universe has expanded 1,000 times in all directions and so the light should now be
2. visible light: 1 m B) microwaves: 1 mm C) microwaves: 1 cm D) radiowaves: 1 m

Draw waves with this wavelength – actual size.

1. Microwaves are invisible to our eyes but they can be detected.
2. How far apart are the hot spots in a microwave oven?
3. The wavelength can be calculated by dividing the speed of the waves - 3.00 x 108 m/s - by the frequency given for the microwave oven - 3450 x 106 Hz.
4. How does the calculated wavelength value compare to the separation of hot spots? Explain.
5. Draw waves with this wavelength – actual size.

d) What other household items can detect the radiation?

1. Physicists predicted that 1-mm microwaves should be hitting the Earth from all directions. These waves were detected by accident. Who should get the Nobel Prize for this discovery - the theorists or the experimentalists? Why?

The Big Bang predicted that the early universe should be very smooth. The CMB is a picture of the early universe and it is incredibly smooth. However, there had to be some unevenness to produce the galaxies and clusters of galaxies that exist. Satellite observations have increased the resolution and contrast of the CMB – especially in the last 20 years.

1. The temperature of the CMB is 2.7254**8** +/- 0.0000**2** K. How does this compare to the roughness of the Earth which has mountains and valleys that vary its radius by +/- 0.1%? The CMB temperature variation is \_\_\_\_\_\_ times smaller than the Earth’s roughness.
2. 10 B) 100 C) 1,000 D) 10, 000
3. The top map shows the microwave data +/- 0.0035 K. It looks like a yin yang symbol in red and blue. The left half is blue and therefore
4. hotter B) colder C) moving toward us D) moving away   
   Explain:

1. When the Doppler Effect due to our movement through space is removed and the sensitivity is increased to +/- 0.00002 K, we see a red band stretching across the centre. This band is due to the radiation from the
2. Earth B) Solar System C) Milky Way D) Local Cluster  
   Explain:

Watch **Minute Physics: Picture of the Big Bang**

<http://www.youtube.com/watch?v=_mZQ-5-KYHw> (Part 1: 0:00 – 2:02, Part 2: 2:02 – 3:06)

**Part 2: What did the Big Bang sound like?**

The CMB is coloured to show the tiny variations in temperature. The red areas are warmer and denser. Sound waves are variations in density. This is a picture of the sound the universe was making 14 billion years ago.

1. The frequency of the sound has been multiplied by 1026 so we can hear it. It has also been modified to show how the sound evolved over the first 760,000 years. <http://faculty.washington.edu/jcramer/BigBang/Planck_2013/BBSnd100.wav> c) John G. Cramer - 2013
2. What happens to the pitch and volume at the start? Why?
3. What will happen to the pitch and volume as the universe continues to expand?
4. both will increase B) both will decrease

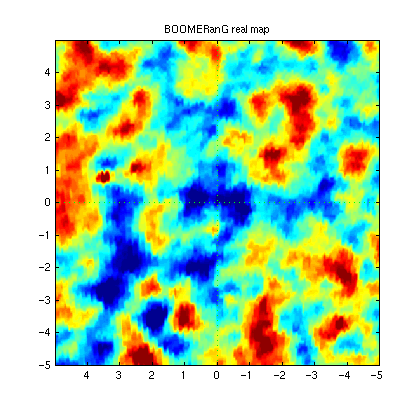
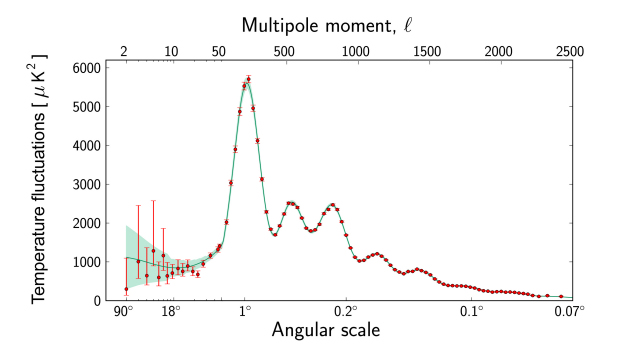
C) pitch will increase, volume decrease D) pitch will decrease, volume increase

Explain:

The universe is not vibrating as a whole. It is many of many little drums. <http://www.youtube.com/watch?v=v4ELxKKT5Rw> video of a resonating rubber circle

<http://www.physics.miami.edu/~nearing/mathmethods/drumhead-animations.html> animations

1. You can calculate the size of the largest ‘drum’. The sound waves were travelling at 2/3 of the speed of light for the 400,000 years since the Big Bang.
2. How far (in light years) could they have travelled? The universe has expanded by 1.000 since then, How big should the ‘drums’ be now?
3. 300 B) 300, 000 C) 3,000, 000
4. The light has been travelling for 14 billion years. This forms the altitude of a long, narrow triangle. (The answer from the previous part is the base of the triangle.) What angle should it make when it reaches us?
5. The 1o spots are the fundamental vibration. Are there other harmonics? If the universe was vibrating like a long spring, what size would the second and third harmonics have?
6. 1/2 o , 1/3 o B) 2 o, 3 o C) 1/2 o , 1/4 o D) 2 o, 4 o



1. The map of the CMB has been analysed to find the harmonics and their strengths. How many harmonics did they find?
2. 2 B) 3 C) 4 D) 5
3. Build a similar wave using the PhET Fourier simulation. How big should the second harmonic be compared to the first?
4. 5800/2500 B) (5800/2500)2 C) (5800/2500)1/2

The waves are a result of gravity pulling matter closer and radiation pressure pushing it apart. The size of the first harmonic can be used to measure the total amount of mass and energy in the universe. This amount is way bigger than all of the stuff we are familiar with – protons, electrons, photons etc. We don’t know what the other 95% of the universe is made of but we know that it comes in two types - dark matter and dark energy.

1. The size of the harmonics indicates how much of the universe is made of each atomic matter, dark matter and dark energy. Dark matter responds to gravity but not to the radiation pressure. Compare standing waves formed by a long spring on the ground vs. one in the air. How does gravity change the wave?
2. How does each type of matter affect the graphs?

<http://background.uchicago.edu/~whu/intermediate/baryons3.html> <http://background.uchicago.edu/~whu/intermediate/driving2.html>

1. The universe `rings` differently if you change the amounts of atoms, dark matter and energy. Go to the **WMAP** **Build a Universe Game** <http://wmap.gsfc.nasa.gov/resources/camb_tool/index.html> Choose “Make full screen in new window”.
2. Move the sliders for atoms, cold dark matter and dark energy to get a good match. What proportions did you need? Hint: The amount of dark energy is greater than dark matter which is greater than atoms and the universe is flat.
3. Is the age of the universe correct? How can you fix that?

For more detail go to <http://wmap.gsfc.nasa.gov/mission/sgoals_parameters_geom.html>

1. The earlier surveys were not able to detect any peaks after the first three. The Planck satellite had greater resolution and clearly shows a fourth and fifth peak. These provide the seeds for the formation of galaxies and clusters of galaxies. <http://cosmicweb.uchicago.edu/filaments.htm> Why does the universe become less smooth?
2. Gravity pulls matter closer and radiation pushes it apart. Stars and galaxies can’t form unless gravity wins. Gravity will only win over radiation if the original density in a given spot is high enough. This will only occur if the average density (Omega\_m, vertical) is high enough and/or if the variation in density (sigma\_8) is great enough. These initial conditions affect what the universe will become. <http://www.learner.org/courses/physics/interactive/lab_interactives/cosmic.html>
3. Set the initial conditions for completely uniform (far left) and the highest desnity (very bottom) value. **Predict** what the universe will look like. **Observe** what the universe looks like and how this appears on the graph.
4. Keep the conditions completely uniform but give it the minimum density (very top).   
   **Predict** what the universe and graph will look like. **Observe** what the universe graph look like.
5. Set the conditions for maximum variation (far right). **Predict** what you will see with minimum density.
6. Set the conditions for maximum variation (far right). **Predict** what you will see with maximum density.
7. What combination best matches our universe?
8. The data from the Planck satellite has provided firm support for the Big Bang, dark matter and dark energy. What problems has it exposed?

For electronic copies of the worksheets, answers and PowerPoint slides go to; <http://roberta.tevlin.ca/workshops/2014%20TDSB%20Cosmology/tsdb%20CMB.htm>

If you have any questions or suggestions, please email me at roberta@tevlin.ca

**Watch out for the new Cosmology resource from the Perimeter Institute. Available in the fall 2014.**

For more information about the details of the CMB try;

1. **Parameters of Cosmology** [http://**wmap**.gsfc.nasa.gov/mission/sgoals\_parameters.html](http://wmap.gsfc.nasa.gov/mission/sgoals_parameters.html) You will find lots more for teachers and students at WMAP’s site
2. Wayne Hu **Ringing in the New Cosmology** 2001  
   <http://background.uchicago.edu/~whu/intermediate/intermediate.html>

This is a very detailed explanation of the power spectrum with lots of analogies and animations. At the time of writing he was describing predictions. These have since been confirmed by WMAP and Planck. Also try his Scientific American article **Cosmic Symphony** 2004 <http://background.uchicago.edu/~whu/SciAm/sym1.html>

1. **Physics for the 21st C: Unit 11: Dark Energy** 2010 (30 minute video) The first half looks at the supernova evidence that the expansion of the universe is increasing. The second half (15:00- 27:00) looks at CMB evidence for dark energy. While you are there, check out the rest of the course on modern physics designed for high school teachers. [http://www.learner.org/courses/**physics**/unit/unit\_vid.html?unit=11](http://www.learner.org/courses/physics/unit/unit_vid.html?unit=11)
2. **Planck’s View of the Universe** 2013 (3:22 minute video)

[http://spaceinvideos.**esa**.int/Videos/2013/10/Planck\_s\_view\_of\_the\_Universe](http://spaceinvideos.esa.int/Videos/2013/10/Planck_s_view_of_the_Universe) You will find lots more for teachers and students at this site of the European Space Agency.