Creating Science – Big Bang and Doppler

How our universe got started and where it is heading.

Suggested Outcomes

(NOTE: This is by no means an exhaustive list of possible outcomes, neither is it intended that ONLY these outcomes can or should be met. Science is a deeply interrelated activity, and you may find cross curriculum links you can and should use.)

Science Inquiry Skills – plan and safely conduct scientific investigations

Nature and Development of Science – people from all over the world, with a range of backgrounds and a great diversity of questions, have contributed to science.

Earth and Space – history of the universe

Physical sciences – light and sound are produced by a range of sources and can be sensed

Science vocabulary words

Tier 1 (Everyday words) – Speed, sun, stars, universe.

Tier 3 (Specialised vocabulary) – The doppler effect, supernova, Big Bang, cosmic background radiation – explained within.

For added maths – frequency, pitch, wavelength.

People to know:

Christian Doppler

Edwin Hubble

Georges Lemaitre

Achievement standard

Science Inquiry Skills – Students observe the Doppler effect, and at upper levels measure it.

Earth and Space – Young students can appreciate the universe and planet earth are OLD, very old. Mature students can create a formal time line of the universe.

Physical sciences – Students observe the Doppler effect, at mid-levels can explain it, and at upper levels can use it to measure the speed of the source of sound.

Nature and Development of Science – students can acknowledge that different scientists contributed to the idea of the Big Bang and cosmic expansion, and at upper levels can intelligently discuss and even disagree with it.

Warning

- LOTS of motion in this activity. PLEASE be extra cautious.
    - Students will be flinging around smart phones, which are expensive and dangerous. Moderate or remove this activity as appropriate.
    - Student will be running around screaming, or riding scooters and bikes. Watch for trip hazard, collisions, and every other danger associated with moving children.

Preparation

Can't wait to see you all at science club on Monday. A few things to bring if you dare.

- Bring a scooter, if you dare risk it, so students can hear the sound go by.
- Bring along a smart phone, preferably one you can risk flinging around a little (or use this simply as a demonstration). You will also need to;
    - Get a tone generator app, such as 'tuning fork'.
    - Get a tone analyser app, such as 'advanced spectrum analyser'.

Understanding sounds and waves can be very helpful to today's lesson.

Suggestions for other year levels

As always, more material is presented here than can be used by the average class during the average lesson time. However, since the students questions can and should guide student learning, more material is presented for you convenience. Remember, it is not uncommon for students to only remember those points which answered their personal questions.

Younger:

Demonstrate the Doppler Effect by playing with spinning sound tubes.

Throw a whistling rocket or similar, such as a whistling football.

Show video of Doppler lines. This is ok:

https://www.youtube.com/watch?v=Kg9F5pN5tlI&feature=youtu.be but the source or observation of the sound wave may be moving, not just the source! And the nearby galaxies are going in all kinds of directions; Andromeda is even going to collide one day. It's only the far galaxies that have red shift, and the further they are, the redder the shift, until they're moving so fast away from us that we cannot see them at all (a point called the event horizon).

Middle:

This activity is aimed at this group

Teen:

Enhance the activity by challenging students to:

- Find other uses of the Doppler effect for sounds (sonar) and light (radar)
- Mathematically calculate the speed of an object making a known sound
- Explain the difference between red shift caused by the Doppler effect, as opposed to red shift caused by the expansion of space.

Learning Intent

Student learning goals

Help students make a self-monitored learning goal for this lesson.

Engage

⇨ Make sure all students write down any questions they may have generated during this phase regarding the topic for today.

Have students safely explore some sound generation toys that involve the Doppler effect, such as spinning sound tubes.

⇨ Note how the sound is high pitched when the tubes are moving towards, and lower when moving away from you. This is because the sound waves are getting bunched up. This is known as the Doppler Effect after the first scientist to study it, Austrian physicist Christian Doppler, who described the phenomenon in 1842.

⇨ If necessary for younger children, demonstrate how sound is made by waves using a balloon and holding the nozzle to feel the vibrations. Explain how the air is wobbling around just like the balloon is; only we cannot see the air.

Explore

⇨ Encourage and validate student explanations of this phenomenon. You may like to ask students to write or draw their explanation personally to avoid embarrassment to students unfamiliar with this material. Remember, 'I don't know' is a valid explanation in science – it is the beginning of learning new things!

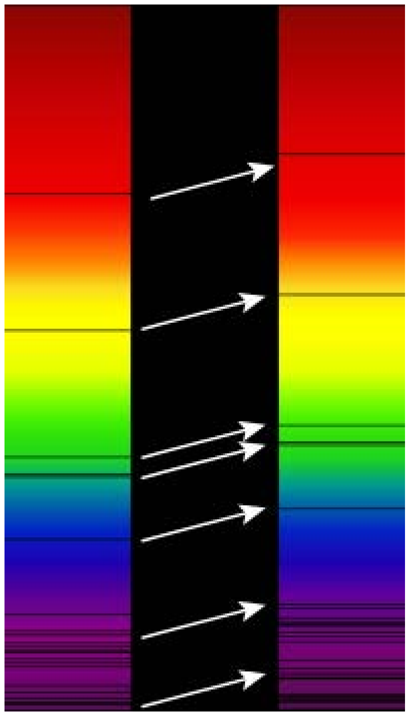
Ask students if they think that light, which is made up of waves like sound, is doing the same thing? Indeed it is, but the light waves are so very fast, our eyes aren't sensitive enough to see it, but we have machines that are sensitive enough to see the Doppler Effect on light. For example, police speed camera's use the Doppler Effect to measure how fast a car is travelling.

⇨ Ask: so as we look up at the stars, we can use their light not only to tell us what they are made of, we can tell if they are moving towards, or further away from us. What do you think they are doing?

Explain

The further away we look, the redder every star becomes…

- ⇨ Why?



The expanding universe

Place 3 dots on an uninflated balloon at the top, middle and side. Ask student to observe what happens to those dots as you inflate the balloon. (They get further and further away). This helps us to understand the expansion of the universe.

The spectrum to the side illustrates red shift. The rainbow on the left is our sun, with well known 'missing colours' due to the absorption of those colours by certain atoms in the sun (helping us know the kinds of atoms that make up the sun.) The rainbow on the right is a distant galaxy, with similar suns that have similar atoms, yet all the absorption lines act as though they are shifted towards the red. How do we interpret this? The galaxy and we are moving away from each other – very, very quickly!

Elaborate

- ⇨ Ask students if they can design new ways to test this explanation, is it really sufficient? Can they think of further or better explanations, and the experiments needed to test them?

The Big Bang

Until the end of the 20th century, scientists thought there were just endless stars going off in every direction forever, ever unchanging and unmoving. (A step up from ancient Greek explanation that stars were considered holes in a giant bowl that allowed 'heavens light' to seep in).

Then along came Edwin Hubble, an American astronomer, who with the invention of the telescope it announced that the dim nebulae that were thought to be 'space clouds' to the naked eye, actually turned out to be distant galaxies. This meant the universe was MUCH bigger than anyone expected. Using Doppler's ideas Hubble noted that the further away we looked, the faster the stars and galaxies were moving away from us (ideas explored earlier by Georges Lemaître and Vesto Slipher).

Going backward in time, it is easy to imagine that these expanding galaxies might have all started in one place. This idea was not lost on Roman Catholic priest Georges Lemaître first noted it in 1927, exploding out from everywhere at once for no reason we can currently imagine, creating all of space, time, matter and energy. This idea was later termed the Big Bang.[1]

[1] In addition to his religious training and work, Georges Lemaître was a physicist who studied the general theory of relativity and worked out some of the conditions of the early cosmos in the 1920s and '30s. His preferred metaphors for the origin of the universe were "cosmic egg" and "primeval atom," but they never caught on, which is too bad, because … Until the 1960s, the idea of a universe with a beginning was

We now think the big bang would have almost exclusively created light elements, Hydrogen, Helium, maybe Lithium: the stuff of stars.

The nuclear furnace in the average sun is capable of creating the heavier elements needed for life: Carbon, Oxygen, Nitrogen, and all the way up to Iron (atom number 26).

However, there is only one naturally occurring event that can create the heaviest elements we find here on earth – Uranium, Lead, etc. And that's an exploding giant star called a Super Nova.

Big bang video - https://www.youtube.com/watch?v=wNDGgL73ihY

Evidence for the Big Bang

1. The further away we look, the older and older galaxies get. At the very edge of our vision we find enormous gas clouds with no heavy elements beyond Lithium because stars haven't had time to form yet – exactly what the Big Bang theory predicts.
2. The Big Bang would have created a lot of 'noise' – enormous heat, radiating everywhere, which would have cooled down to barely microwaves by now. Looking about, that's what we find, then *cosmic background radiation* in every direction we look.
3. Using Red shift, we can see that the universe is expanding, distant objects moving away from each other in a manner similar to what might be observed after an enormous explosion.

However, as with all science, this does not mean the theory is complete, end of discussion! We still don't know HEAPS about how and when things happened, not to mention why it all happened in the first place. The questions about the Big Bang outweigh all that we currently know about the Big Bang. There's much to learn, and it means we need to keep an open mind, and keep asking questions!

Discuss the time line of the Universe

13.8 billion years ago – the Big Bang.

Before that, we don't know. Physics as we know it breaks down.

After that, everything expanding at faster than the speed of light.

5 billion years ago – the galaxy begins to form

Along with many others. The first stars tend to be huge and short lived, forging the elements of which other stars, planets, and indeed people, are made from.

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controversial among physicists. The name "Big Bang" was actually coined by astronomer Fred Hoyle, who was the leading proponent of an *alternative theory*, where universe continues forever without a beginning.

[Lemaitre's] shorthand for the theory caught on, and now we're kind of stuck with it. Calvin and Hobbes' attempt to get us to adopt "horrendous space kablooie" has failed so far. From https://www.symmetrymagazine.org/article/five-facts-about-the-big-bang 8 Feb 18

4.6 billion years ago – the solar system begins to form[2]

Our solar system, like probably several in the local cluster, must have formed from the remnants of a giant sun going supernova. This would have formed a massive cloud around 65 light years across. Maybe a million years later, another compression wave from another supernova may have kick started that cloud into forming the massive accretion discs that became our solar system, and several others. However, our solar system has travelled around the galactic centre at least 20 times since then, so it's difficult to trace who our solar system's siblings (and parent) may be.

3.5 billion years ago – life begins on earth.

Although we may be a billion years late on this estimate!

In 5 billion years' time – the slow catastrophe

The Andromeda galaxy will 'collide' with the Milky way, and while very few actual collisions are expected, the sun will likely find a new path to follow in the new extra-large galaxy – if the entire solar system isn't flung out into intergalactic space (which won't be a problem for us, we expect).

However, by that time, our sun will swell up to a red supergiant, and probably swallow earth.

1 trillion years from now

Or thereabout, all the stars in the universe are expected to have burnt out but a few, with only a few glowing 'embers' of stars remaining, including our sun as a white dwarf. Everything will be further away from each other than even now, and it might be tricky to keep life going! Perhaps, by then, we'll figure out how to create a new universe! Or maybe the universe is creating enough matter from subspace that the stars will keep forming and shining forever, it's impossible to say anything definitive at this point.

Explore the Doppler Effect

Try the activity in the appendix.

Advanced: The universe

The universe is so big, and getting bigger, that light has not had (nor will it ever have) enough time to cross the universe from one side to another (more than 46 billion light years across, maybe even infinitely more[3]). This makes for some weird science when we talk about Elsewhere, but that's really complex stuff.

It means that from our perspective there's a point, far away in every direction, that light has not yet had time to get to us. This is called the 'event horizon', because beyond that point, we not only have NO IDEA what is happened, or has happened, but unless the learn to travel faster than light we will NEVER KNOW.

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[2] Video - History of earth via asteroid Benu https://www.youtube.com/watch?v=x1QTc5YeO6w

[3] Edge of universe, edge horizon - https://www.youtube.com/watch?v=hw8noakRT7w

High school: Redshift due to the expansion of space is NOT ONLY due to the Doppler Effect.

Redshift due to the expansion of space is NOT ONLY due to the Doppler Effect, but also because, as space between us and distant galaxies 'grow', the photons of light stretch out just a little more.

Also, redshift can occur as light is moving away from a gravitational object, the gravity stretching space-time and making the light redder. Of course, light travelling into a gravitational field tends to get bunched up and bluer, even as the object emitting the light is getting faster and faster.

Calculate speed using pitch

The relationship between the speed of sound, its frequency, and wavelength is the same as for all waves:

$$v = f\,\lambda$$

where v is the speed of sound (in units of m/s), f is its frequency (in units of hertz), and λ is its wavelength (in units of meters).

Use this table https://pages.mtu.edu/~suits/notefreqs.html to get the wavelength of the sound, but BE SURE you convert to meters, not centimetres, by multiplying by 100.

So at 440 hertz from your phone comes out at about 460hertz, meaning:

x = 460 * 78.41

= 358

Then 358 m/s minus 345 m/s means

The source of the sound was travelling *at about*[4] 13 m/s at the time.

Evaluate

- ⇨ Review with students what the felt they learnt from this unit. Did they have any questions at the start that they feel were answered?

Success criteria

- ⇨ Review the Learning Intentions of this lesson with students. Was it met?

Summative:

Help students consider ways they can communicate their new understanding to others, just as scientists need to do.

- Do a dramatic presentation on the history of the universe, including key ideas such as the Big Bang, expansion, Doppler Effect, supernova's, nebulae, accretion discs and solar system.

[4] The speed of sound in air is affected by a number of factors, including temperature, humidity and air pressure, making our results, at best, an approximation.

- Create a formal experimental write up on using the Doppler Effect to determine the speed of object creating a known note. Use the maths provided. Explain how this can help us in other ways, such as sonar, police scanners, and detecting universal expansion.

So what?

Knowing where the universe came from is a key, unanswered, question in science.

Creating science

Science content

Earth and Space – history of the universe

Physical sciences – light and sound are produced by a range of sources and can be sensed

Science inquiry skills

Science Inquiry Skills – plan and safely conduct scientific investigations

Science as a human endeavour

Nature and Development of Science – people from all over the world, with a range of backgrounds and a great diversity of questions, have contributed to science.

Appendix: The Doppler Effect

Swing a phone around…

Appendix: Calculate speed using pitch

The relationship between the speed of sound, its frequency (pitch), and wavelength is:

$$v = f \lambda$$

where v is the speed of sound (in m/s), f is its frequency (in units of hertz), and λ is its wavelength (in meters).

The wavelength of your average 440 hertz wave (an "A") in air is .7841 meters (or 78 cm long)

And that wave is travelling through the air at around 345 meters ever second.

Fill in the {blanks} to find out how fast you moved your tone maker:

Speed = {frequency in hertz (look on device)} times .7841

Then subtract this speed from 345 (the normal speed of sound in air) to find the speed the tone maker was moving at the time it was making the sound.

<u>*For example:*</u>

The sound from your phone comes out at about 460hertz, meaning:

x = 460 * .7841

= 358

Then 358 minus 345 makes 13, so…

The source of the sound was travelling *at about*[5] 13 meters per second at the time.

[5] The speed of sound in air is affected by a number of factors, including temperature, humidity and air pressure, making our results, at best, an approximation.