

Using the 'Unlocking the Universe in 3D' Virtual Reality program

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STUDENT WORKSHEET #1

1. Write down all the words you know describing things in the Universe.
2. Use the Internet to go to NASA's 'What is the Universe website'
<https://science.nasa.gov/exoplanets/what-is-the-universe/>

[illegible]

LESSON 1: The components and scale of the Universe

STUDENT WORKSHEET #2

Cosmic Survey: What are your ideas about the Universe?

Question 1: How big?

With your group, arrange the 7 images side by side, in a row, **in order of actual size** of the object (or group of objects) pictured. Order the images so that the smallest is on the left, largest on the right. When your group is satisfied that you have the best order, record the **names** of the objects in the spaces below:

Objects Ordered by Actual Size						
_____	_____	_____	_____	_____	_____	_____
1.	2.	3.	4.	5.	6.	7.
Smallest in Actual Size			Largest in Actual Size			

Question 2: How far?

With your group, arrange the 7 images side by side, in a row, **in order of distance** of the object from Earth. Order the images so that the object closest to Earth is on the left, farthest on the right. When your group is satisfied that you have the best order, record the **names** of the objects in the spaces below:

Objects Ordered by Distance from Earth						
_____	_____	_____	_____	_____	_____	_____
1.	2.	3.	4.	5.	6.	7.
Closest to Earth			Farthest from Earth			

Question 3: How old?

With your group, arrange the 7 images side by side, in a row, **in order of age** of the object, beginning with the youngest (most recently formed) object, and moving in order to the oldest. When your group is satisfied that you have the best order, record the **names** of the objects in the spaces below:

Objects Ordered by Age						
_____	_____	_____	_____	_____	_____	_____
1.	2.	3.	4.	5.	6.	7.
Youngest (Most Recently Formed)			Oldest			

LESSON 2: Modelling the Universe

STUDENT WORKSHEET

Universe Model Analysis

A model is a simplified imitation of something that helps us understand it better. Because a model is not the real thing, it can misrepresent certain features of the real thing. Different models may represent only part of what is being modelled.

After your group creates your model, you will be asked to explain your model to the rest of the class, commenting on these four questions:

1. What features of the Universe does your model represent?
2. What things does your model misrepresent?
3. What things about the universe does your model omit, or not represent?
4. What questions came up as your group worked on your model?

Use this chart to record the features of your model as your group is working (one person could be a scribe).

Features represented	Misrepresented or irrelevant features	Features of the real thing omitted by the model
Questions we had:		



LESSON 3 (VR): Basic training and console training

STUDENT WORKSHEET

Console training

You have collected data on three different space objects during the U3D console training.
Using the snapshots of the data fill in the following information:

SPACE OBJECT DATA

Space Object 1:

Mass ($M_{\odot}$): _____

Temperature (K): _____

Space Object 2:

Number of protons: _____

Number of neutrons: _____

Number of electrons: _____

Atomic number: _____

Mass number: _____

Atomic mass: _____

Net charge: _____

Spectrograph printout:

Space Object 3:

Mass ($M_{\odot}$): _____

Temperature (K): _____

Spectrograph printout:

Questions:

Based on the visual information and the information collected by the scanner (in your table above), please answer the following questions:

1. Order the space objects from smallest to largest:
2. Which object is the hottest?
3. Which object is the coolest?
4. What type of space object do you think each object is? Can you identify each one by name?
5. What element do you think Space Object 2 is? Why do you think this?

LESSON 4: Basics of the Big Bang

STUDENT WORKSHEET

Scientific theories and evidence

1. List the scientific theories mentioned in the video 'Why science is NOT 'just a theory'.
2. List the three things that scientists mean when they say the word 'theory':
 - 1.
 - 2.
 - 3.
3. In the video 'Evidence for the Big Bang', what did Olber conclude about the Universe?
4. Which poet/thinker disagreed with Olber's conclusion that the Universe must be infinite?
5. What assumption did Einstein make, thereby erroneously believing that the Universe was infinite and static?
6. What did Einstein's own general theory of relativity require spacetime to be?
7. Who published results that were used to demonstrate that the Universe is indeed expanding?
8. Which competing model proposed that the Universe was expanding, but has the same properties at all times?
9. Which piece of evidence resulted in scientists adopting the Big Bang Theory as the standard model of cosmology?

10. Because this radiation was detectable in every direction and not associated with any particular source, where is its origin?
11. What else can we use CMB radiation and recession velocities for?
12. What other things does the model predict?
13. What do we use particle accelerators for?
14. What do we use bubble chambers for?

LESSON 5 (VR): The Oldest Light activity – Nucleosynthesis

STUDENT WORKSHEET

Oldest Light

Research Task 1: Exploring subatomic particles 10-20 seconds after the Big Bang.

What are the four different sub-atomic particles at **20 seconds** after the Big Bang?

Using the data you collected in 'The Oldest Light' activity in VR fill in the following table:

Subatomic Particle	Mass (amu)	Charge (no units)	Information

Research Task 2: Exploring the first nuclei 2-20 minutes after the Big Bang.

1. What happened during the Big Bang Nucleosynthesis?
2. What nuclei had formed at **2 minutes** after the Big Bang?

Using the data you collected in 'The Oldest Light' activity in VR fill in the following table:

Nucleus	Number of protons	Number of neutrons	Information about nucleus
Hydrogen-1 (^1H)			
Hydrogen-2 (^2H)			

Hydrogen-3 (^3H)			
Helium-3 (^3He)			
Helium-4 (^4He)			
Lithium-7 (^7Li)			
Beryllium-7 (^7Be)			

3. Draw each nucleus (red for protons, blue for neutrons)

4. What do you notice about the naming of each nucleus?

5. What do the nuclei have in common?

6. What does the number next to the name indicate?

Research Task 3: Formation of nuclei in the Big Bang.

Questions:

- How has the temperature of the Universe changed from 2, 3 and 20 minutes after the Big Bang? (hotter, colder – by how much?).

Complete the table below from the data you collected.

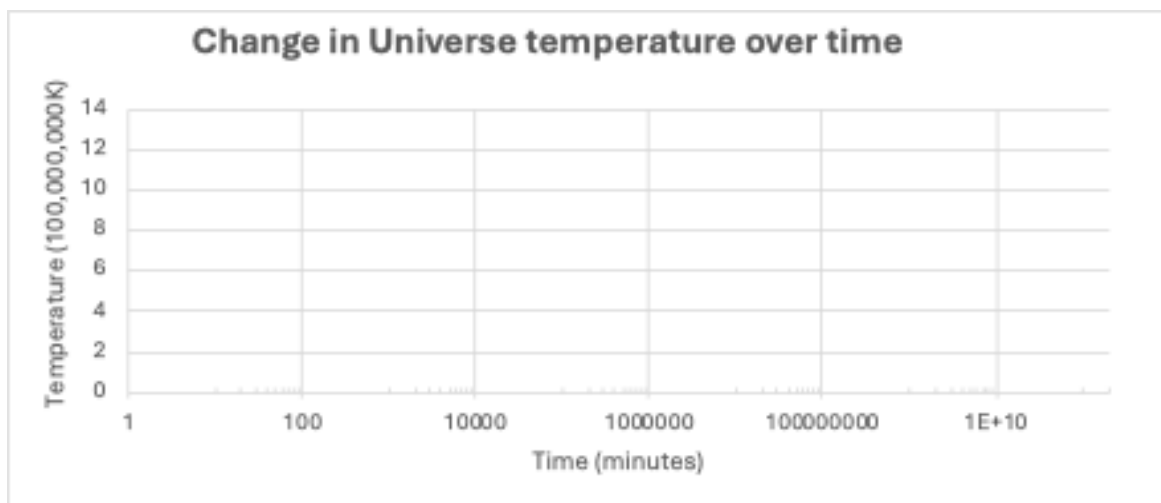
Time	Temperature (K)
2 (minutes)	
3 (minutes)	
20 (minutes)	
380,000 (years) = _____ mins	

The time the temperatures are taken goes from minutes after the Big Bang to hundreds of thousands of years. You will need to convert years to minutes, which will give you an answer that uses scientific notation (e.g., 3.8×10^5).

HINT: use

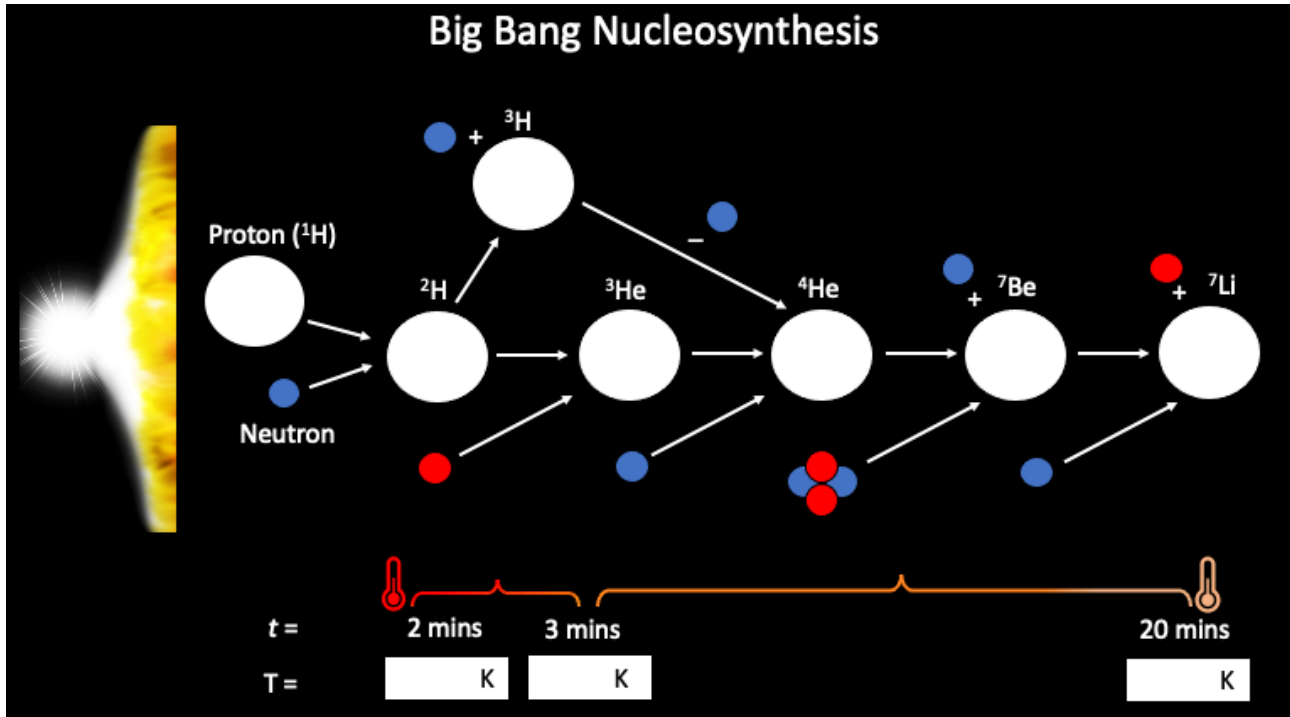
<https://www.google.com/search?q=convert+years+to+minutes>

- Use the data from the table above to plot the change in temperature in degrees Kelvin (horizontal axis) over time (in minutes). You are dealing with *huge* variations in numbers, so you will have to note the following:
 - The highest temperature is in billions of degrees Kelvin, and the lowest is in single digits. This means your vertical axis (temperature) is measured in billions of degrees Kelvin, and the smaller numbers will look very close to zero).
 - To fit all this into a graph that makes sense, we use a logarithmic scale on the horizontal axis. Instead of equal increments, we use a power of 10—each value increases by a factor of 10.



- Join your plotted data points to see the changes over time.

4. Using the data you collected on the Big Bang Nucleosynthesis in VR, complete the graphic below by drawing the elements' nuclei and the temperature at which they formed.



Isotopes that can form:

- Deuterium (one proton and one neutron in a nucleus)
- Tritium (one proton and two neutrons in a nucleus).
- Helium-3 (two protons and one neutron in a nucleus)
- Helium-4 (two protons and two neutrons in a nucleus).
- Beryllium-7 (four protons and three neutrons). The Beryllium changes into lithium quickly because it is unstable.
- Lithium: Lithium-7 (three protons and four neutrons).

Questions:

1. Only the nuclei of simple atoms had formed at this stage of the Universe. Why are there no electrons in shells or electron clouds?
2. How did heavier elements than this (the rest of the periodic table) form? When did this start to occur?

LESSON 6: Evidence for the Big Bang – The Cosmic Microwave Background

STUDENT WORKSHEET

The Cosmic Microwave Background

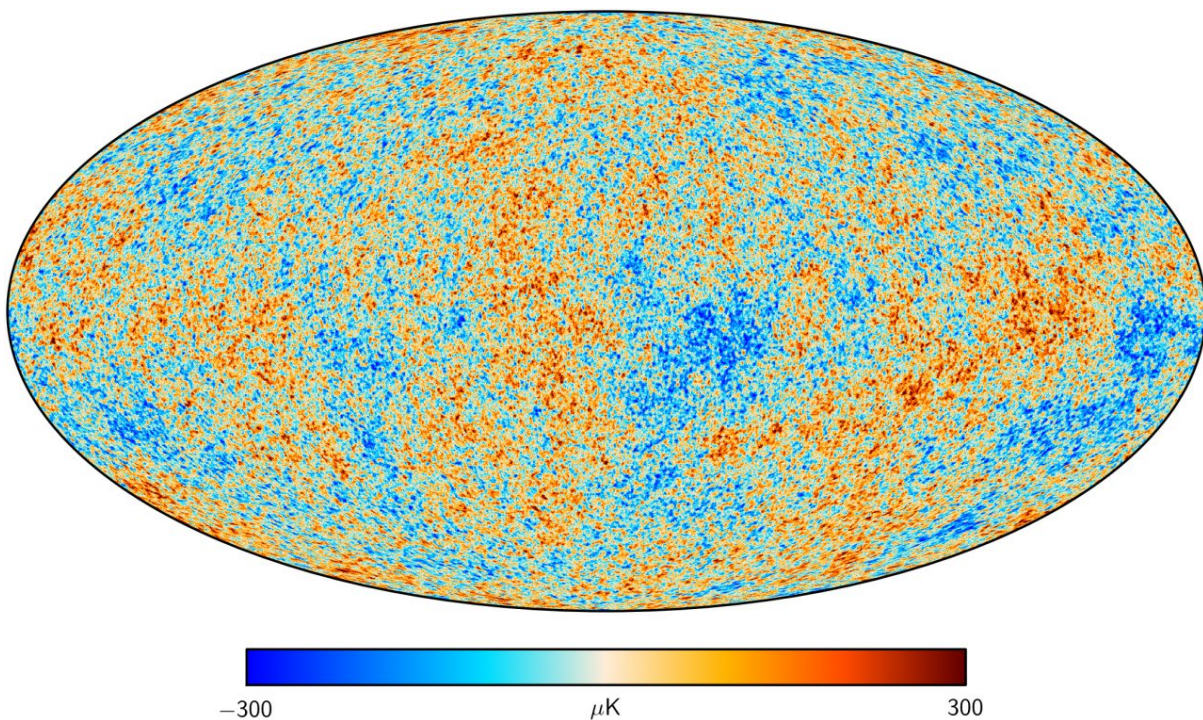
Watch the video 'Picture of the Big Bang (a.k.a Oldest Light in the Universe) – Minute Physics', YouTube, <https://www.youtube.com/watch?v=mZQ-5-KYHw&t=0s> (4.00 min) (stop at 3.12 min).

Questions:

1. How long has the Cosmic Background Radiation been travelling to Earth?
2. Based on the instruments that observe this 'light', what part of the electromagnetic spectrum is the light travelling in when it reaches Earth?
3. What's the proper name for the 'red-hot cosmic soup' of protons, neutrons and electrons shown in the video? (you might have to Google it or ask your teacher!)
4. At what temperature did the protons and electrons finally connect to each other?
5. Why was the light released from the electrons when they became attached to protons to form hydrogen atoms?
6. The light from the freed photons gets stretched from what sort of light?
7. What is the temperature of empty space?
8. What is our best understanding of the small and seemingly random but noticeable bumps in the Universe at that time?
9. These hot or cold spots were hotter or colder than their surroundings by a factor of what?
10. These tiny variations eventually coagulated and coalesced to form what?

In the Oldest Light activity in VR, you recorded the tiny fluctuations in temperature between the warmest parts of the CMB (red) and the coldest parts (dark blue). Copy those numbers into the table below.

Temperature	Red CMB	Dark Blue CMB	Variation in temperature
Kelvin (K)			
Celsius (°C)			



Questions:

1. The small temperature differences are presented in this “map” of the CMB using the WMAP satellite and observations from the Teide Observatory. It is called an **anisotropy map**. What does the word ‘anisotropy’ mean?
2. What is causing these very tiny fluctuations in temperature in the CMB?
3. If the blue spots are colder, is the matter there **more or less dense** than the warmer red spots?
4. Why is the pattern of the CMB important? What do scientists think is the link between the density of matter (and dark matter) and the evolution of the Universe?

LESSON 7: The Electromagnetic Spectrum, spectra and redshift

STUDENT WORKSHEET

Light: Crash Course Astronomy #24

Questions:

1. If light is a wave, what are the things doing the 'waving'?
2. What is the distance between the crests in a wave called?
3. What is the link between wavelength and energy?
4. Which colour light has the shortest wavelength? Which has the longest?
5. Which part of the electromagnetic spectrum can our eyes see?
6. What sort of electromagnetic waves have the shortest wavelengths (and most energy)? Which ones have the longest wavelengths (least energy)?
7. What is one way for matter to get rid of energy?
8. What do astronomers call light with a shorter wavelength? What about a longer wavelength?
9. What analogy can we use to describe the very specific volumes of space around a nucleus that an electron is allowed to occupy?
10. What happens when an electron steps down to a lower energy state?
11. If different atoms have different 'staircases', how can we tell what atom it is when an electron jumps down a step?
12. What is a spectrometer?
13. If an object in space is headed toward you, what happens to the wavelength of light emitted from the object? What about if it is headed away from you?
14. What is the spoiler alert in the video?
15. What are some things spectroscopy allows us to analyse in astronomy?

LESSON 8 (VR): Exploring the First Atoms in the Cosmic Dark Ages

STUDENT WORKSHEET

Research Task 1: The five stable atoms of the neutral Universe.

Complete the table using the data you collected in VR.

Name	No. Protons	No. Neutrons	No. Electrons	Atomic Number	Mass Number	Atomic Mass (amu)	Net Charge
Hydrogen-1 (¹ H) atom							
Hydrogen-2 (² H) atom							
Helium-3 (³ He) atom							
Helium-4 (⁴ He) atom							
Lithium-7 (⁷ Li) atom							



The standard symbol for an isotope of an element consists of the element symbol and two numbers: the mass number and atomic number. This is illustrated by two of the isotopes of carbon (symbol: C).

Questions:

1. What do you notice about the number of protons in an atom and its atomic number?
2. Does the atomic number change for different isotopes of the same atom (e.g. Hydrogen-1 vs Hydrogen-2)?
3. Does the number of neutrons affect the atomic number?
4. Does the number of neutrons affect the mass number?
5. What is the difference between the mass number and the atomic mass of an isotope? (you may have to get help with this – ask your teacher or look it up):
6. What do you notice about the net charge of all of these atoms? What would happen if you added electrons?

Research Task 2: Spectra of the neutral atoms.**Questions:**

1. Refer to the snapshots you took of each neutral atom's spectra. Identify the frequency of each emission line for each atom and record the data in the table below.

Element	Line 1 (Hz)	Line 2 (Hz)	Line 3 (Hz)	Line 4 (Hz)
Hydrogen-1				
Hydrogen-2				
Helium-3				
Helium-4				
Lithium-7				

2. Why do Hydrogen-1 and Hydrogen-2, and Helium-3 and Helium-4 have exactly the same spectra?
3. What causes the spectral emission lines (you might need to look back at your answers in Lesson 7).
4. How do astronomers use the emission spectra from stars and galaxies?

Research Task 3: Build your own atoms.

Draw the five models of the neutral atoms you built in VR.

LESSON 9 (VR): The Epoch of Reionisation – Exploring the EoR and the first stars

STUDENT WORKSHEET

Research Task 1: What happened during the Epoch of Reionisation?

Questions:

4. What is happening during the Epoch of Reionisation (EoR)? Circle your answer.
 - A. The Universe remained cold, dark and featureless.
 - B. Planets were formed for the first time.
 - C. The first stars and galaxies emitted UV light. The Universe became transparent.
 - D. The Universe stopped expanding for 600 million years.
2. In a paragraph summarise the transition of the Universe from the Cosmic Dark Ages to the end of the Epoch of Reionisation?

Research Task 2: the first stars

Complete the table using the data you collected in VR.

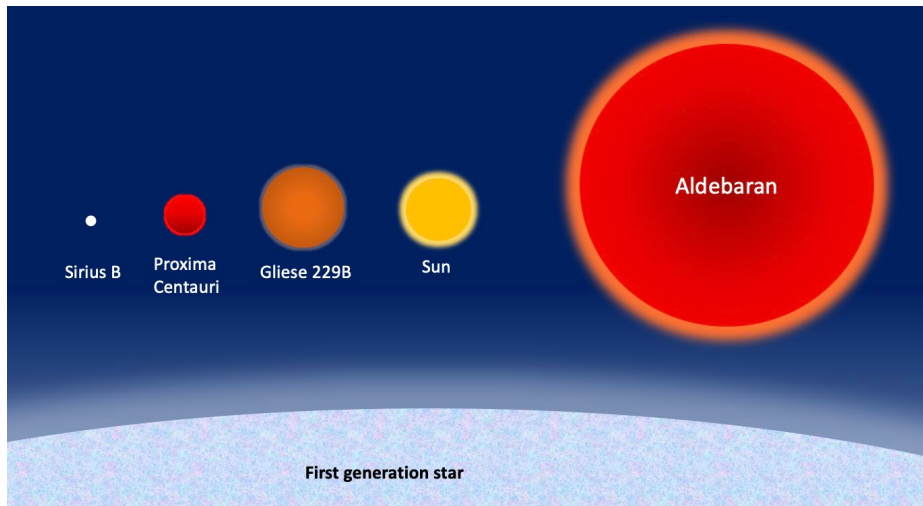
Property	Star #1	Star #2	The Sun
Radius ($R_{\odot}$)			
Luminosity (million $L_{\odot}$)			
Lifespan (million years)			
Composition			
Temperature (K)			
Mass ($M_{\odot}$)			

Questions:

Using this website - 'What were the first stars like?', Webb Space Telescope website, <https://webbtelescope.org/contents/articles/what-were-the-first-stars-like> and the data you have collected above, answer the following questions on what the first stars were like compared to our Sun and how they influenced the Epoch of Reionisation.

1. How many years after the Big Bang did the first stars start to form?

2. Astronomers call the first stars in the Universe 'Population III' stars. What elements were in Population III stars? How does this compare with our Sun?
3. How big (or massive) were Population III stars compared to the mass of our Sun?



The largest stars in the present-day universe are a couple hundred times more massive than our sun. The first stars could have had as much as 100,000 times the Sun's mass. (Adapted from Merrill Sherman/Quanta Magazine)

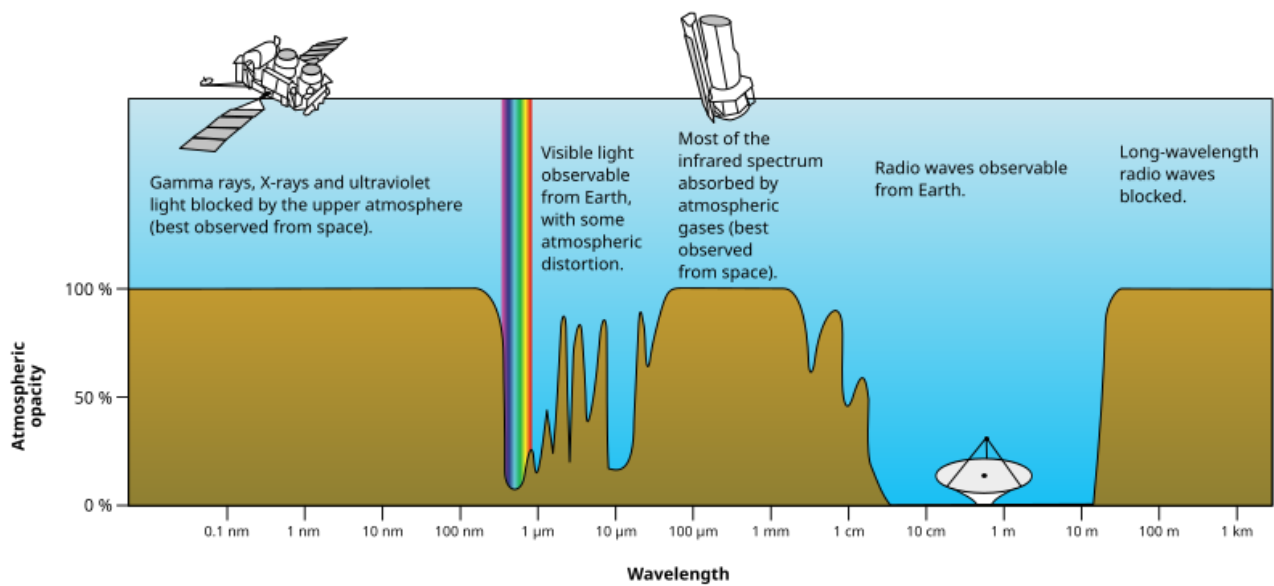
4. How long did the first stars live for? How does that compare to the expected lifespan of our Sun?
5. Temperature and brightness of a star are directly related to what?
6. If the first stars were 100 times the mass of our Sun, what would be the surface temperature and the brightness (luminosity) of the first stars?
7. If the first stars were extremely hot and bright, what sort of energy did they give off? What did that light energy do to surrounding fog of neutral hydrogen that filled the Universe during the Cosmic Dark Ages?
8. What do computer models show happened to the first stars that were greater than 10 and less than about 140 times the mass of the Sun (how did they die)? What would remain of these stars?
9. What would have happened to even larger metal-free stars (up to about 300 solar masses)?
10. If we could use space telescopes, like the Hubble or JWST, to look back into space-time and see billions of light years away from us, what part of the electromagnetic spectrum would astronomers be looking at to see ancient galaxies that contain first-generation stars, given the light has been redshifted and stretched from the UV radiation they are emitting?

LESSON 10 (VR): Signal from Cosmic Dawn – the 21 cm line

STUDENT WORKSHEET

Signals from Cosmic Dawn

A significant advantage radio astronomers have over IR, UV and high-energy astronomers is the atmospheric window. Our atmosphere is completely transparent to radio waves, so we don't need to send large radio antennas to space (like we usually have to do with IR/UV/high-energy astronomy satellites) in order to efficiently expose our instruments to the sky.



Electromagnetic opacity of the Earth's atmosphere (Wikimedia Commons)

You have collected data from four points in space-time. Use the information from your snapshots to complete the following table. In the dashed boxes, draw the models of the waves you saw.

	340 million years after the BB (beginning of EoR)	1 billion years after the BB (end of EoR)	6 billion years after the BB	13.8 billion years after the BB
Wavelength	Emission 1			
Wavelength	Emission 2			
Wavelength	Emission 3			

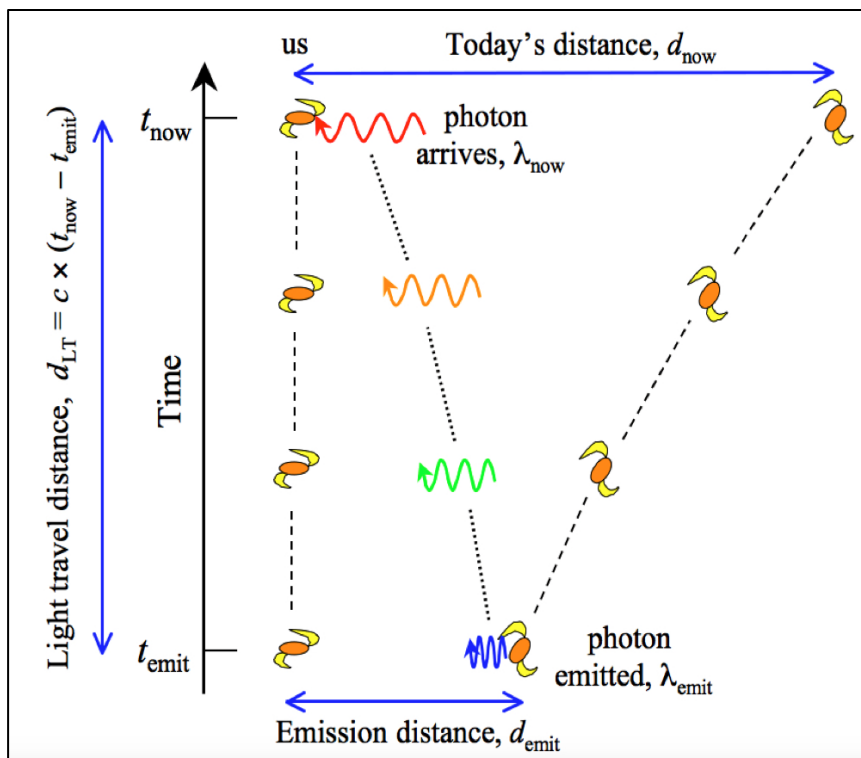
Take a note of the “z =” number:

Time after Big Bang	Redshift (z)
340 million years	
1 billion years	
6 billion years	
13.8 billion years	

Research questions:

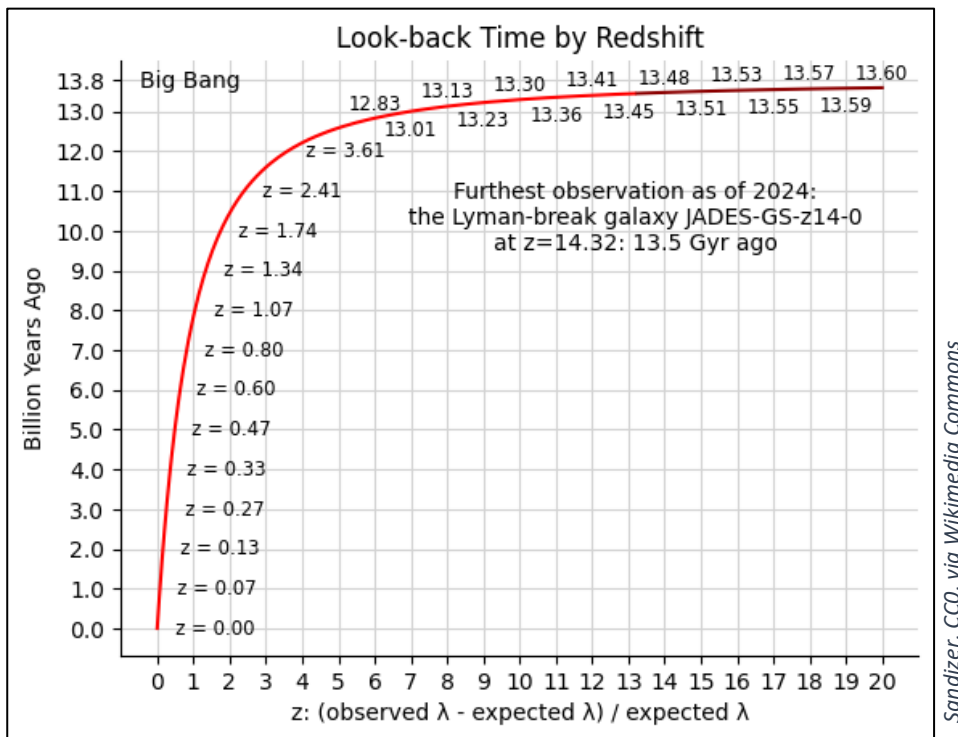
1. What created the red wave?
2. Where did it originate?
3. How far has it travelled?

Here is some information to help you answer this question: In astronomy, a **light year** is the distance light travels in a year (roughly 9.46 trillion kilometres) and so is a unit of **distance**, not of time. Because the Universe is expanding, the distance between objects is expanding, too. The distance travelled by the photons is called the **light travel**. This is shown in the diagram below:



Distances in cosmology

We can work out how far that photon has travelled to us using this diagram:



- If our photon from the red line has a z value of 13 at the present time, use the graph above to calculate how many billions of years it has travelled:
- Use the Omni Light Year Calculator <https://www.omnicalculator.com/physics/light-year> to work out how many light years the photon has travelled – use billion years (byrs) for time and light years (1y) for distance:

4. Has it changed over time?

5. If so, what caused this change?

LESSON 11: New technologies to uncover the answers to big questions in modern astrophysics

STUDENT WORKSHEET

New technologies to uncover the answers to Big Questions on modern astrophysics

Technological advancements have expanded our ability to observe the Universe and contributed to building a better understanding of it. Advances in telescopes, spectroscopy, imaging, and computational astrophysics, as well as our recent ability to explore space, have given us many new insights into the Universe.

Fifty years ago, cosmologists did not know if there was a big bang. Now, we can draw quite precise inferences back to a nanosecond. So, in fifty years, debates that now seem flaky speculation may have been firmed up. But it is important to emphasize that progress will continue to depend, as it has up till now, ninety-five percent on advancing instruments and technology—less than five percent on armchair theory, but that theory will be augmented by artificial intelligence and the ability to make simulations.

Use the scaffold on the next page to:

- Research *one* of the astrophysics new technologies, and
- Evaluate the impact this technology has had on expanding our understanding of the Universe.
- Use the information collected in the scaffold to present a **research report** on the impact of new technology on astrophysics.

Technologies

Ground-based Optical, Infrared and Radio Telescopes:

VLT - Very Large Telescope <https://www.eso.org/public/teles-instr/paranal-observatory/vlt/>

MWA – Murchison Widefield Array <https://www.mwatelescope.org/>

ASKAP – Australian Square Kilometre Array Pathfinder Telescope <https://www.csiro.au/en/about/facilities-collections/atnf/askap-radio-telescope>

SKAO – Square Kilometre Array Observatory <https://www.skao.int/en>

SPT – The South Pole Telescope <https://pole.uchicago.edu/public/Home.html>

VLTi – Very Large Telescope Interferometer <https://www.eso.org/public/teles-instr/paranal-observatory/vlt/vlti/>

Keck I and II Telescopes <https://www.keckobservatory.org/our-story/telescopes/>

Gemini <https://www.gemini.edu/>

ALMA – Atacama Large Millimeter/submillimeter Array <https://www.eso.org/public/teles-instr/alma/>

ELT – Extremely Large Telescope <https://elt.eso.org/>

Giant Magellan Telescope <https://giantmagellan.org/>

Space Telescopes:

Hubble Space Telescope <https://www.stsci.edu/hst>

James Webb Space Telescope (JWST) <https://www.stsci.edu/jwst>

Fermi Gamma-ray Space Telescope <https://science.nasa.gov/mission/fermi/>

Chandra X-ray Observatory <https://www.nasa.gov/mission/chandra-x-ray-observatory/>

Lynx X-ray Observatory <https://www.lynxobservatory.com/#home-section>

Instruments and supercomputer simulations:

MUSE – Multi Unit Spectroscopic Explorer (on the VLT)

<https://www.eso.org/sci/facilities/paranal/instruments/muse.html>

XSHOOTER – spectroscopic instrument on the VLT

<https://www.eso.org/sci/facilities/paranal/instruments/xshooter.html>

SAMI – Sydney-AAO Multi-object Integral-field unit <https://sami-survey.org/node/11>

GALAH – GALactic Archeology with HERMES <https://www.galah-survey.org/>

Millenium Simulation Project <https://wwwmpa.mpa-garching.mpg.de/galform/virgo/millennium/>

Illustris simulations <https://www.illustris-project.org/>

DRAGONS simulations <https://www.ph.unimelb.edu.au/~smutch/dragons-media.html>

Evaluate the impact your chosen technology has had on expanding our understanding of the Universe

Evaluate: make a judgement based on criteria; determine the value of:

Name and location (if application) Who is providing the funding? What is it being used for? What has it discovered so far?	Description of the technology:	
	Points for (advantages) of using this technology:	Points against (limitations) of using this technology:
	AND	
What does this technology need to have or have achieved to be successful in helping us understand the Universe? What is your overall judgement or conclusion with using this technology?		