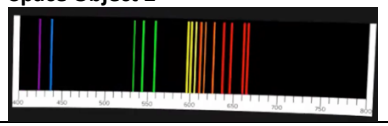
OUTLINE OF TASKS IN VR AND ASSOCIATED SNAPSHOTS

Basic training and console training

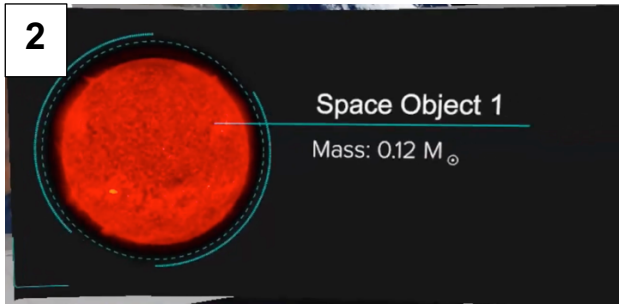
Task or information	Location for snapshot	#	Snapshot of what
BASIC TRAINING			
Induction Checklist *1) Teleport around the Transporter Room* *2) Discover the U3D Universe timeline* *3) Put on your spacesuit* *4) Use the U34D wristband*	No snapshot required		
	No snapshot required		
Induction Checklist *2) Discover the U3D Universe timeline*	No snapshot required		
Induction Checklist *3) Put on your spacesuit* • *Teleport to stand in front of spacesuit cabinet* • *To put on your space suit, point either controller at the cabinet and while holding down the side trigger, press the front trigger.*	No snapshot required		
Induction Checklist 4) *Press the buttons on the wristband with your extended pointer finger.* *[camera icon]* ***Camera*** *to take snapshots of your results and measurements.* *[U3D icon]* ***Return to Transporter Room*** *after completing a research task.* *[Earth icon]* ***Return to Earth*** *to analyse your research data.* *Take a snapshot of Kirsten now. Remember also to save the image.*	Kirsten on right side of the console	1	Kirsten (avatar)
CONSOLE TRAINING			
Practice Session *Press each highlighted button to get data and information on every space object. Remember to take snapshots of your results.* *1) Scan the space object.* *2) Press each highlighted button*			

	Monitor/console	2	**Space Object 1** Mass: 0.12 $M_{\odot}$
	Monitor/console	3	**Space Object 1** Temperature: 3,042 KC
	Monitor/console	4	**Space Object 2** 
	Monitor/console	5	**Space Object 2** Eight protons, eight neutrons, eight electrons Atomic Number: 8 Mass Number: 16 Atomic Mass: 15.999 amu Net charge: -2
	Monitor/console	6	**Space Object 3** 
	Monitor/console	7	**Space Object 3** Mass: 1 trillion $M_{\odot}$
	Monitor/console	8	**Space Object 3** Temperature: Between 12 K and 41 K

TRAINING SNAPSHOTS

1

2



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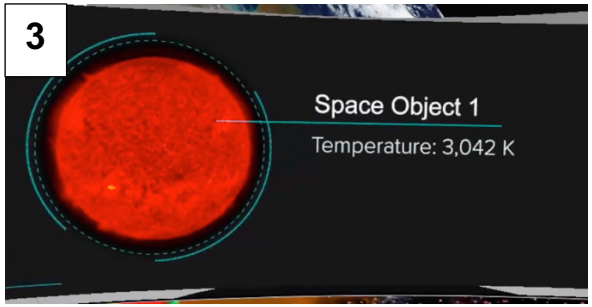

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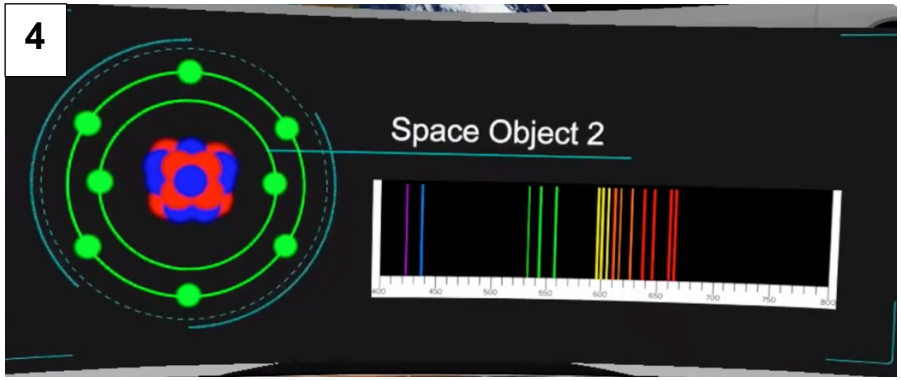

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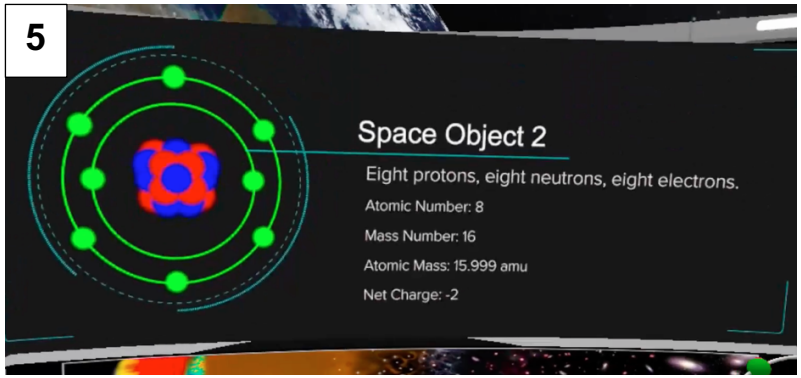

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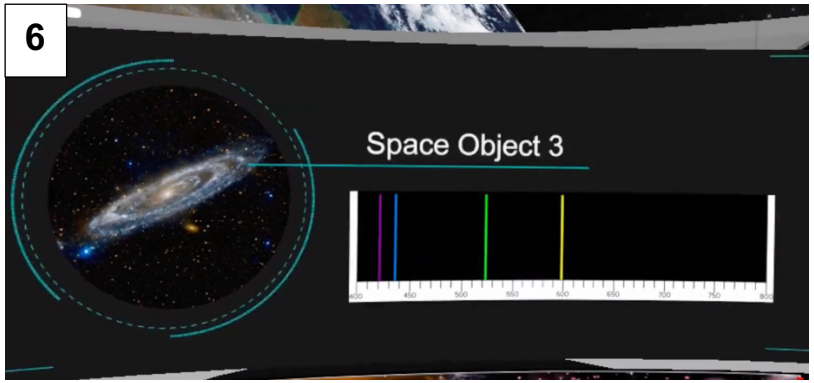

Space Object 3

7


Space Object 3
1 trillion $M_\odot$

8


Space Object 3
Temperature: Between 12 K and 41 K

1. Oldest Light

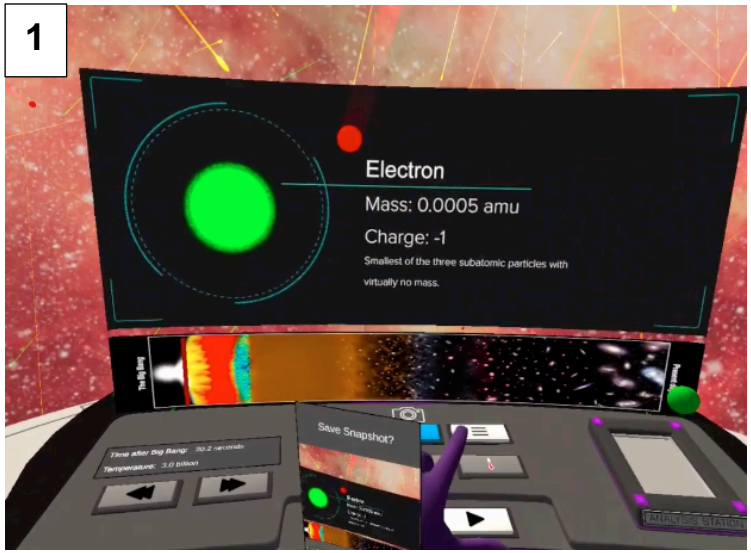
Research task	Location for snapshot	#	Snapshot of what
Research Task 1: *What four subatomic particles existed ~20 seconds after the Big Bang.* *Press [ff] to go to ~20 seconds then press [pause]* *Scan a particle, then press the [atom] button for more information. Repeat for each particle.* (#1, 2, 3, 4 not necessarily in this order)	Monitor/console	1	Electron – info + model ***Electron*** *Mass: 0.0005 amu* *Charge: -1* *Smallest of the three subatomic particles with virtually no mass.*
	Monitor/console	2	Proton – info + model ***Proton*** *Mass: 1.0072 amu* *Charge: +1* *Every element has at least one proton.*
	Monitor/console	3	Neutron – info + model ***Neutron*** *Mass: 1.008 amu* *Charge: 0* *Neutrons are important for the stability of nuclei, except in the single-proton hydrogen nucleus.*
	Monitor/console	4	Photon – info + model ***Photon*** *Mass: 0* *Charge: 0* *Photons get their energy from their momentum.* *If an object with no mass is to physically exist, it can never be at rest.*
Research Task 2: *What nuclei formed between 2 minutes and 20 minutes after the Big Bang?* *Use the [ff], [rewind], [pause] and [play] to control time.* *Find and scan each nucleus, then press the [atom] button for more information. The model of each nucleus will appear on the bench.* *HINT: When nucleosynthesis ceased, there were seven different nuclei.* *CHALLENGE: Can you scan the atoms in the order they formed?* (#5 – 11 not necessarily in this order)	Monitor/console	5	1H nucleus – info + model ***Hydrogen-1 nucleus*** *One proton* *The most common isotope of hydrogen, it is also a stable subatomic particle. Also called a protium.*
	Monitor/console	6	2H nucleus – info + model ***Hydrogen-2 nucleus*** *One proton, one neutron.* *Stable isotope of hydrogen. Also called heavy hydrogen or a deuteron.*
	Monitor/console	7	3H nucleus – info + model ***Hydrogen-3 nucleus*** *One proton, two neutrons* *Unstable isotope of hydrogen with a half-life of 12 years. Decayed into helium-3. Also called a triton.*

	Monitor/console	8	3He nucleus – info + model ***Helium-3 nucleus*** *Two protons, one neutron* *A light, stable isotope of helium. The only stable isotope of any element with more protons than neutrons (with the exception of protium).*
	Monitor/console	9	4He nucleus – info + model ***Helium-4 nucleus*** *Two protons, two neutrons* *The most common isotope of helium and very compact, it is 20% smaller than a deuteron.*
	Monitor/console	10	7Be nucleus – info + model ***Beryllium-7 nucleus*** *Four protons, three neutrons* *Unstable isotope of beryllium (half-life of 53 days). Decayed into lithium-7.*
	Monitor/console	11	7Li nucleus – info + model ***Lithium-7 nucleus*** *Three protons, four neutrons* *Stable and most abundant isotope of lithium.*
Research Task 3: *What is the order of formation of the nuclei during the Big Bang nucleosynthesis and at what temperatures did they form?* *1) Scan a nucleus from the bench and then scan its corresponding position on the BBN graphic.* *2) Use the [ff] and [reverse] buttons to find out the temperature of the Universe at 2, 3 and 20 minutes after the Big Bang. When you identify the temperatures, scan their correct positions in the BBN graphic.*	BBN graphic at right + models on bench	12	BBN graphic when complete
	BBN graphic at right	13	Addition of three temperature/times on BBN graphic
Research Task 4: *1) What was the temperature of the Universe 380,000 years after the Big Bang?* *2) What happened to the nuclei and electrons?* *Take snapshots as evidence.*	Console - temperature/time	14	Temperature/time gauge showing temperature
	Background	15	Atoms floating above or around console
In Transporter Room These tasks will only come up if task button is pushed.	Monitor/console	16	Red wave - info and model

			Cosmic Microwave Background *Red* *Temperature: 2.7251 K* *Frequency: 160 GHz* *Wavelength: 1.9 mm*
	Monitor/console	17	Blue wave - info and model *Cosmic Microwave Background* *Dark Blue* *Temperature: 2.7250 K* *Frequency: 160 GHz* *Wavelength: 1.9 mm*

OLDEST LIGHT SNAPSHOTS

1



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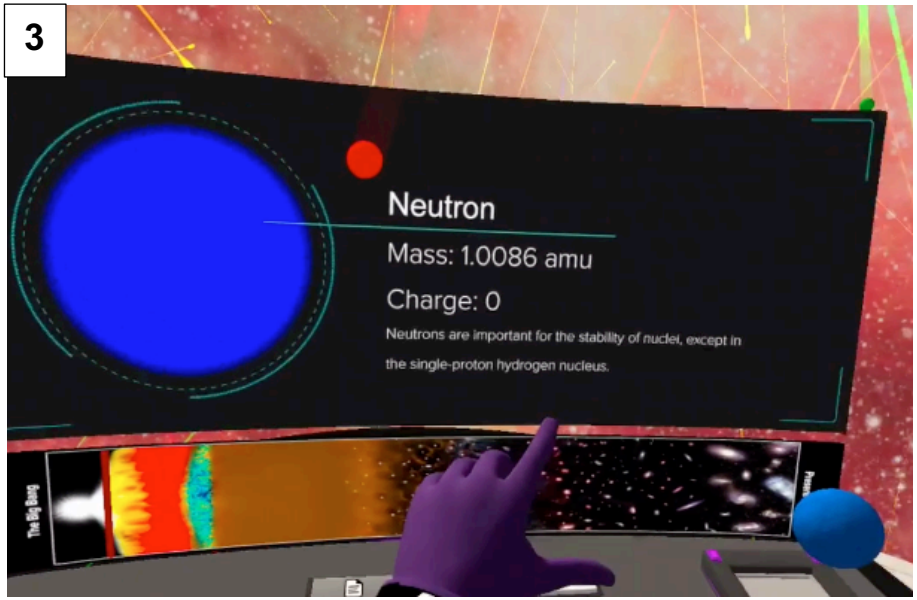
3



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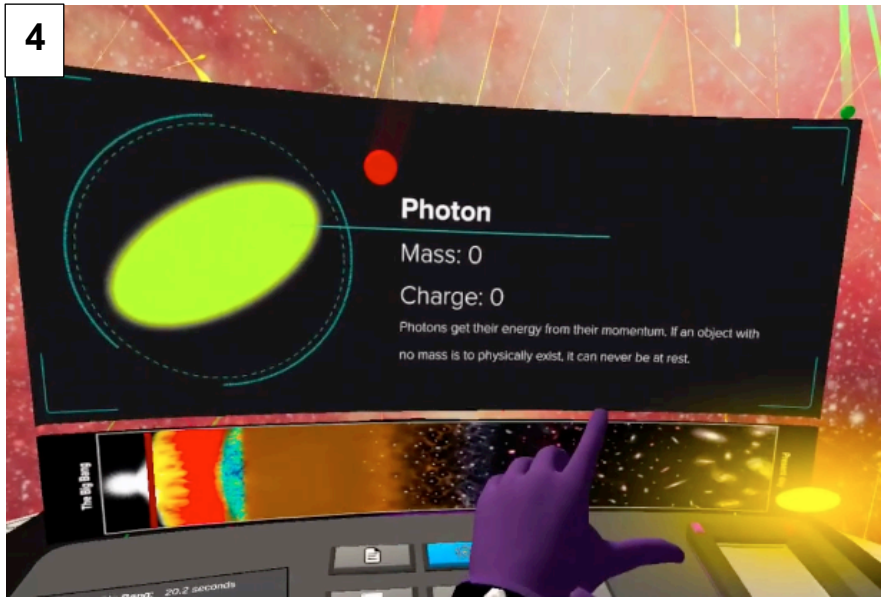

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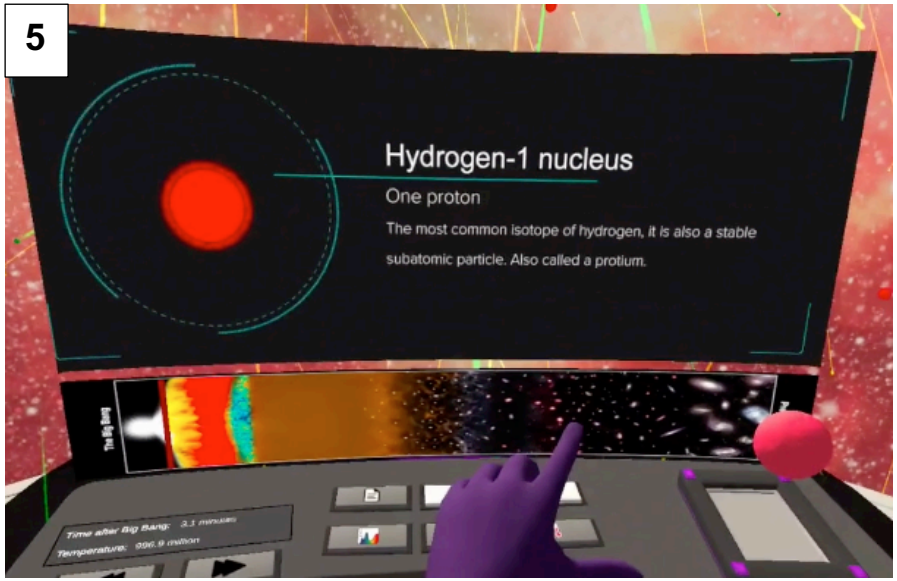
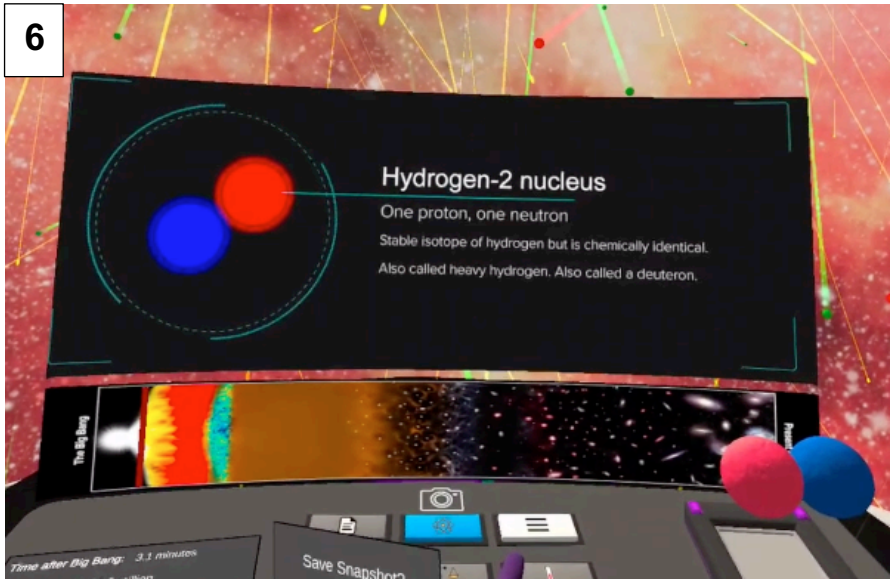
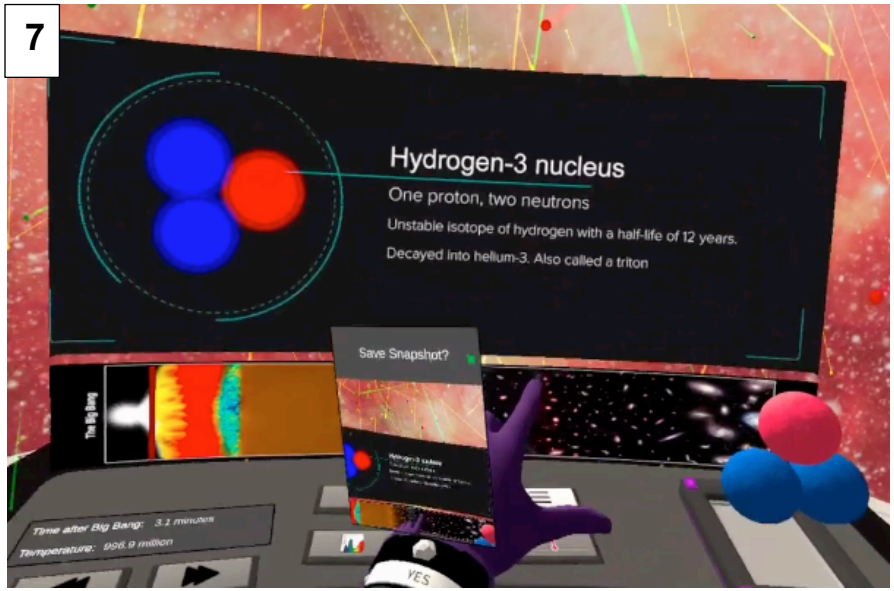

Hydrogen-1 nucleus
One proton
The most common isotope of hydrogen, it is also a stable subatomic particle. Also called a protium.

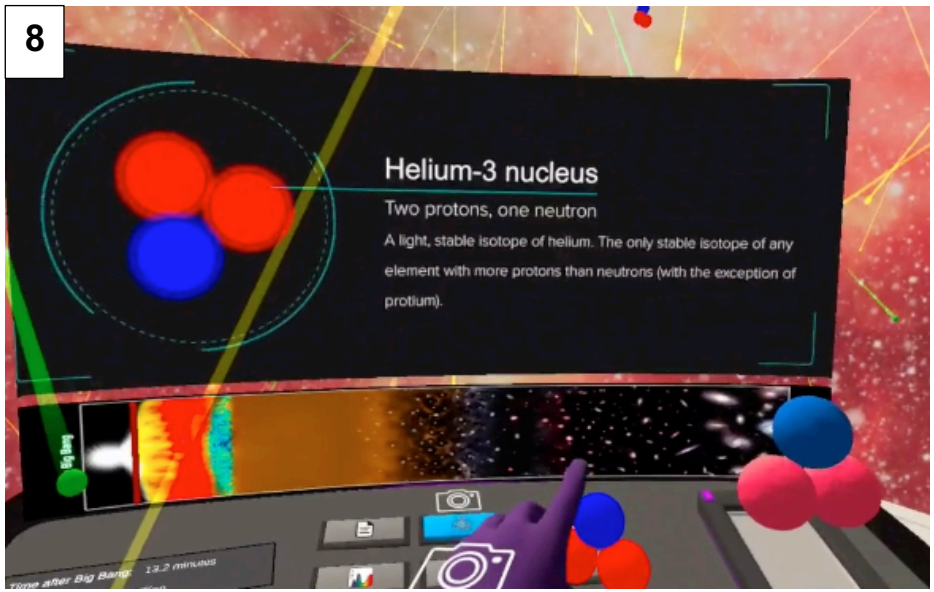
6


Hydrogen-2 nucleus
One proton, one neutron
Stable isotope of hydrogen but is chemically identical.
Also called heavy hydrogen. Also called a deuteron.

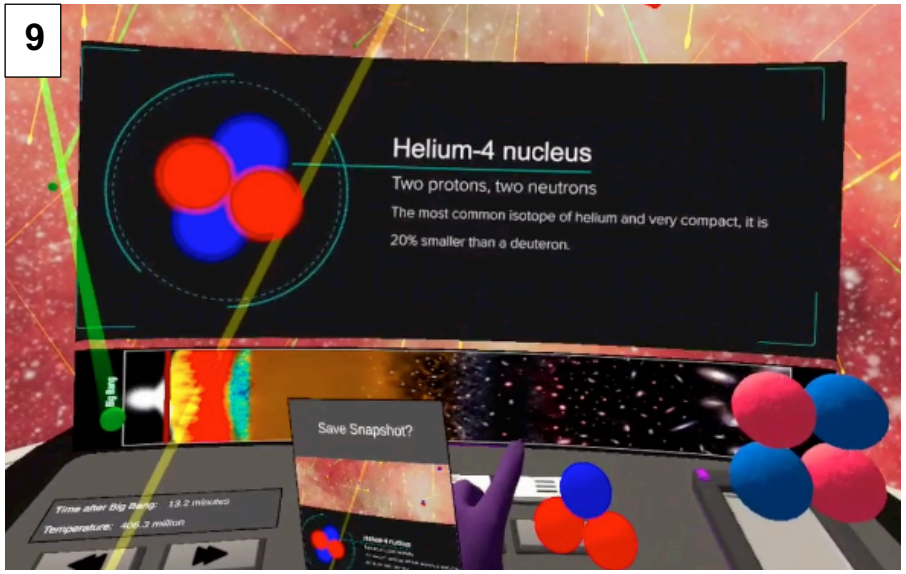
7


Hydrogen-3 nucleus
One proton, two neutrons
Unstable isotope of hydrogen with a half-life of 12 years.
Decayed into helium-3. Also called a triton
Save Snapshot?

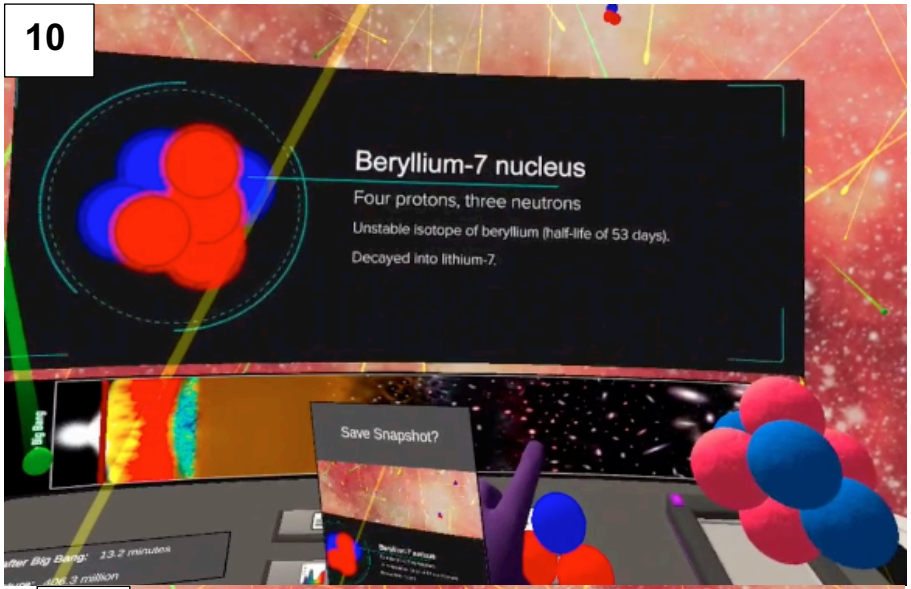
8


Helium-3 nucleus
Two protons, one neutron
A light, stable isotope of helium. The only stable isotope of any element with more protons than neutrons (with the exception of protium).

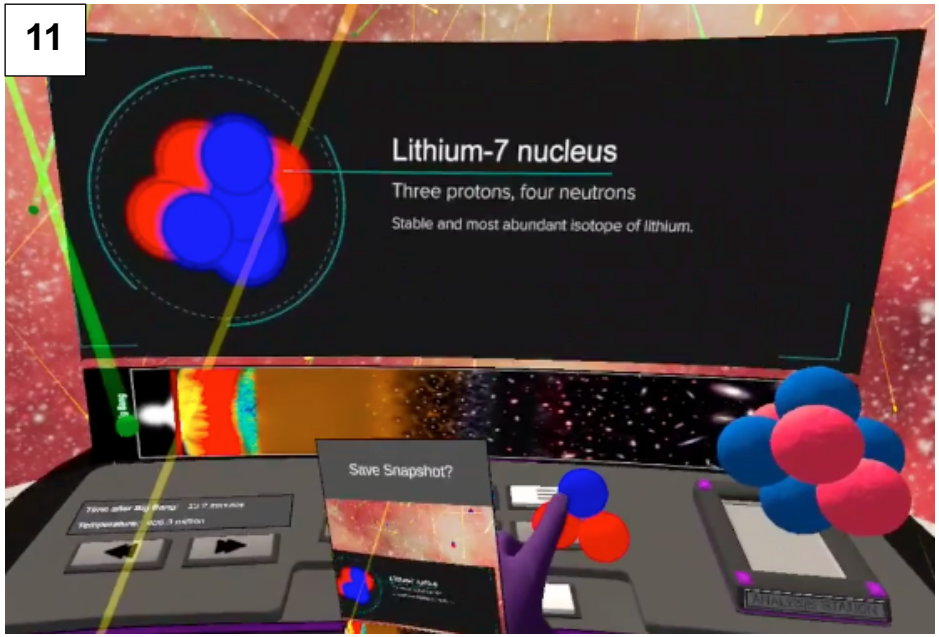
9


Helium-4 nucleus
Two protons, two neutrons
The most common isotope of helium and very compact, it is
20% smaller than a deuteron.
Save Snapshot?

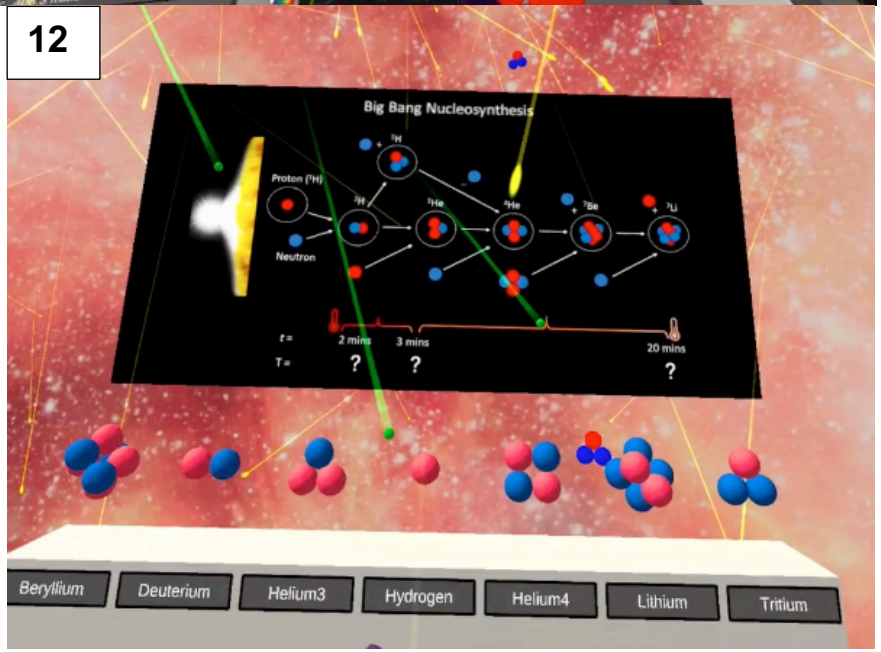
10


Beryllium-7 nucleus
Four protons, three neutrons
Unstable isotope of beryllium (half-life of 53 days).
Decayed into lithium-7.
Save Snapshot?

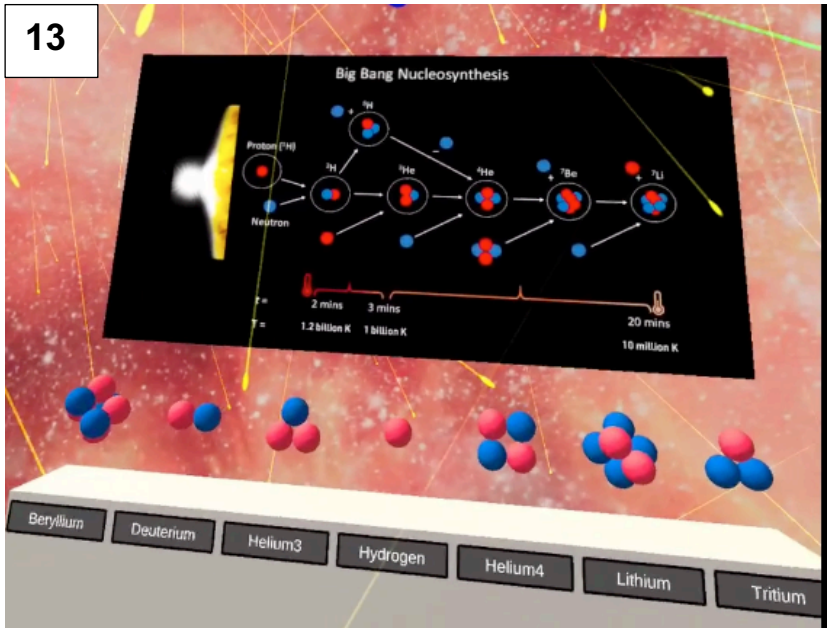
11


Lithium-7 nucleus
Three protons, four neutrons
Stable and most abundant isotope of lithium.
Save Snapshot?

12


Big Bang Nucleosynthesis
Proton (¹H)
Neutron
2 mins
3 mins
20 mins
Beryllium
Deuterium
Helium3
Hydrogen
Helium4
Lithium
Tritium

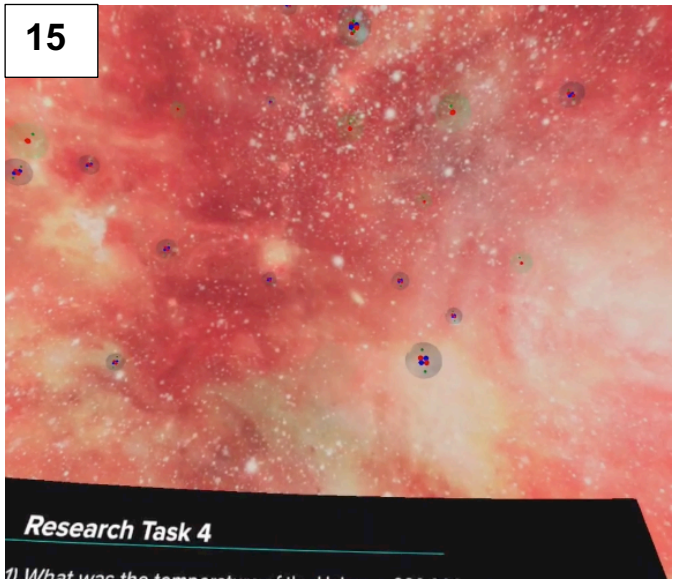
13


Big Bang Nucleosynthesis
Proton (¹H)
Neutron
²H
³He
⁴He
⁷Be
⁷Li
2 mins
3 mins
20 mins
1.2 billion K
1 billion K
10 million K
Beryllium
Deuterium
Helium3
Hydrogen
Helium4
Lithium
Tritium

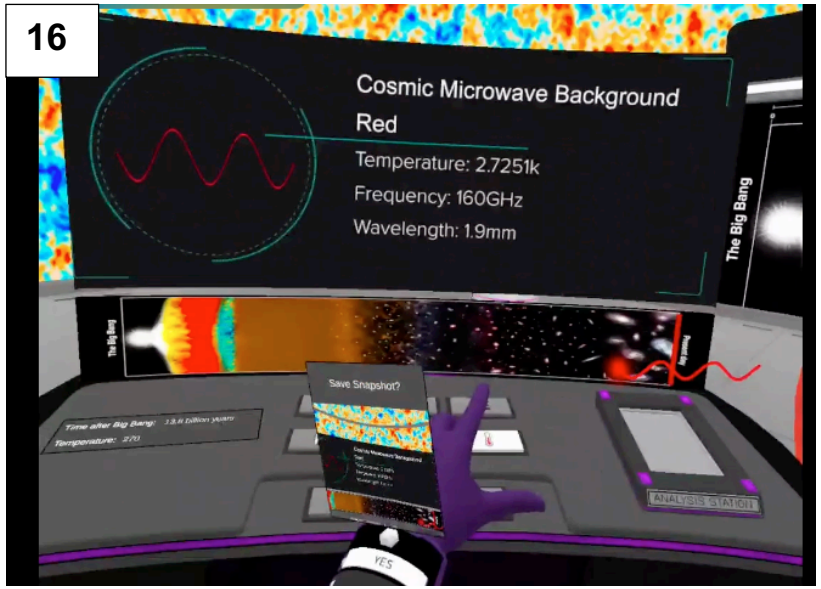
14


Time after Big Bang: 380.0 thousand years
Temperature: 3,000
Save Snapshot?

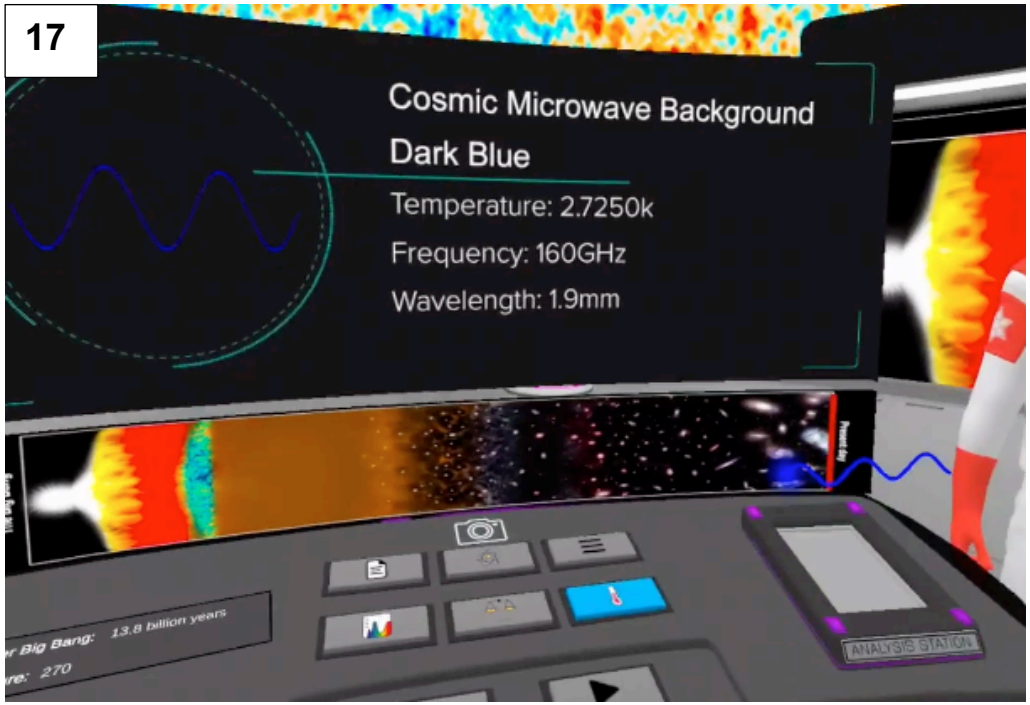
15


Research Task 4

16


Cosmic Microwave Background
Red
Temperature: 2.7251k
Frequency: 160GHz
Wavelength: 1.9mm
The Big Bang
Save Snapshot?
YES

17


Cosmic Microwave Background
Dark Blue
Temperature: 2.7250k
Frequency: 160GHz
Wavelength: 1.9mm
Big Bang: 13.8 billion years
270
ANALYSIS STATION

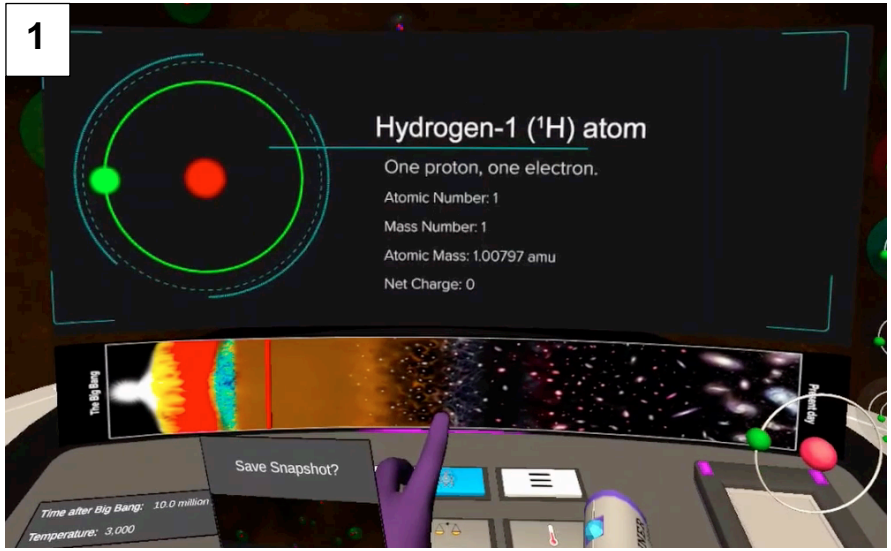
2. Exploring the first atoms in the Cosmic Dark Age

Research task	Location for snapshot	#	Snapshot of what
Research Task 1: *What are the five stable neutral atoms in the Cosmic Dark Ages?* *Scan an atom then press the [atom] button for more information. Repeat for each atom.* *HINT: A couple of atoms will be harder to find. Use the models on the right of the monitor to help.* (#1 – 5 not necessarily in this order)	Monitor/console	1	1H atom – info and model ***Hydrogen-1 (^{1}H) atom*** *One proton, one electron.* *Atomic number: 1* *Mass number: 1* *Atomic mass: 1.00797 amu* *Net charge: 0*
	Monitor/console	2	2H atom – info and model ***Hydrogen-2 (^{2}H) atom*** *One proton, one neutron, one electron.* *Atomic number: 1* *Mass number: 2* *Atomic mass: 2.01410 amu* *Net charge: 0*
	Monitor/console	3	3He atom – info and model ***Helium-3 (^{3}He) atom*** *Two protons, one neutron, one electron.* *Atomic number: 2* *Mass number: 3* *Atomic mass: 3.01603 amu* *Net charge: 0*
	Monitor/console	4	4He atom – info and model ***Helium-4 (^{4}He) atom*** *Two protons, two neutrons, two electrons.* *Atomic number: 2* *Mass number: 4* *Atomic mass: 4.00260 amu* *Net charge: 0*
	Monitor/console	5	7Li atom – info and model ***Lithium-7 (^{7}Li) atom*** *Three protons, four neutrons, three electrons.* *Atomic number: 3* *Mass number: 7* *Atomic mass: 7.01600 amu* *Net charge: 0*
Research Task 2: *What are the spectral properties of each atom?*	Monitor/console	6	1H spectra and mode
	Monitor/console	7	2H spectra and model

Scan an atom then press the [spectrum] button. Repeat for each atom. (#6 – 10 not necessarily in this order)	Monitor/console	8	3He spectra and model
	Monitor/console	9	4He spectra and model
	Monitor/console	10	7Li spectra and model
Research Task 3: *Build your own atoms.* *Scan and then replicate each type of atom by using the sub-atomic particles in the tubs on your left. Each model will then appear on the bench.* (#11 – 15 not necessarily in this order)	Console – left side	11	1H model
	Console – left side	12	2H model
	Console – left side	13	3He model
	Console – left side	14	4He model
	Console – left side	15	7Li model
Research Task 4: *What is the order of abundance of the five atoms?* *Scan an atom on the bench and then scan its correct percentage label. Continue with the other atoms.*	Bench	16	Matched atoms and abundances
Research Task 5: *Where do each of the atoms fit on the Periodic Table?* *Scan an atom on the bench and then scan its position on the Periodic Table. Continue with the other atoms.*	Bench	17	Matched atoms, abundances and elements

EXPLORING ATOMS SNAPSHOTS

1



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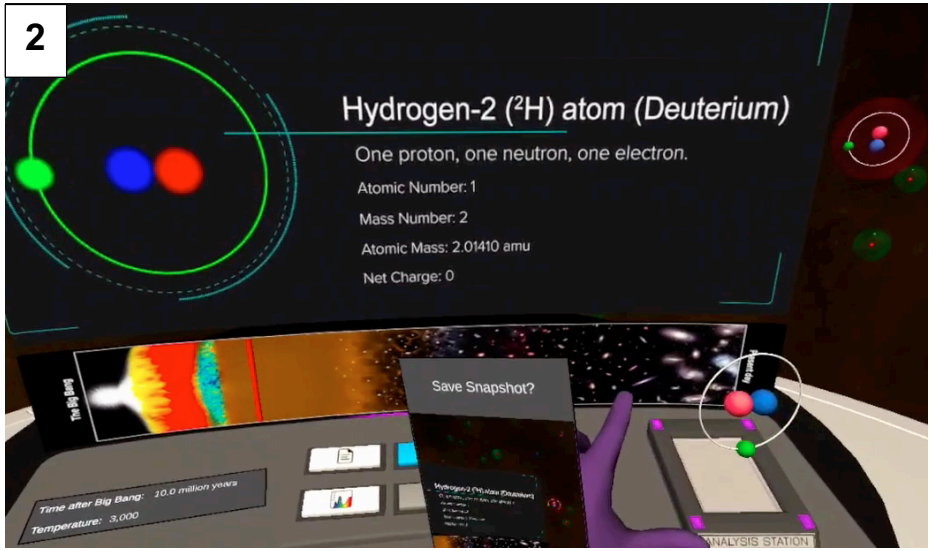

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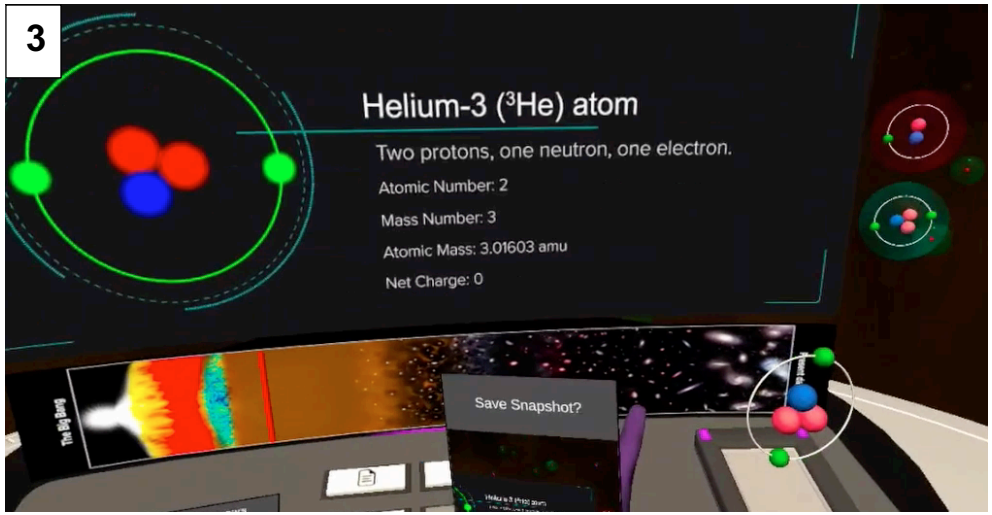

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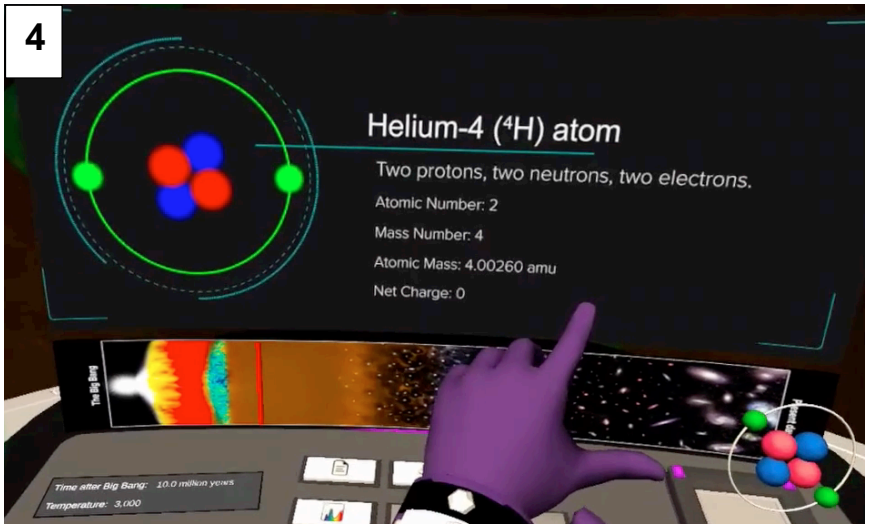

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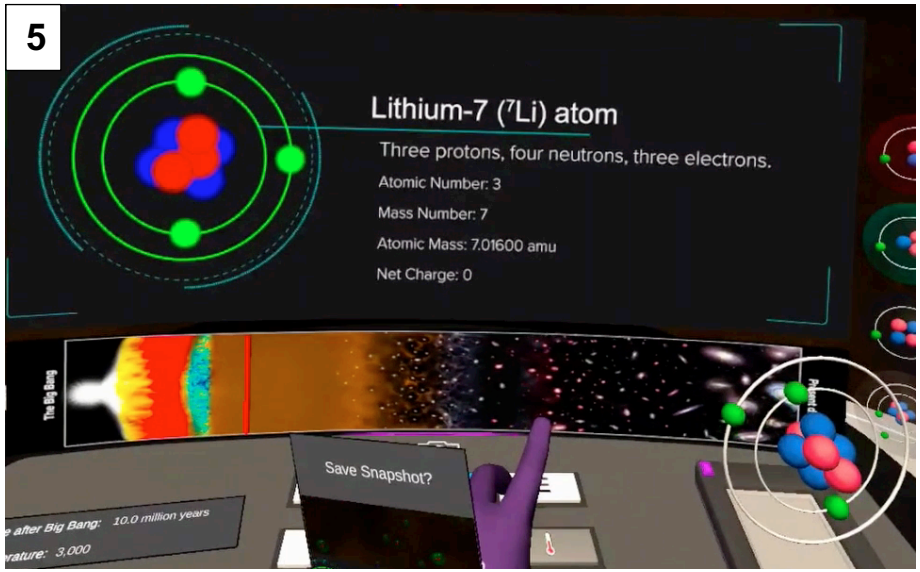
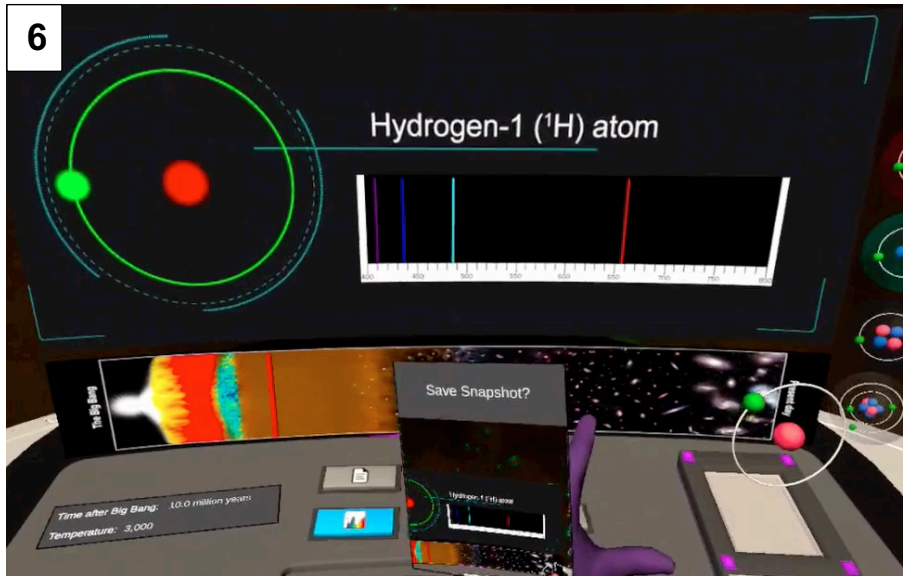
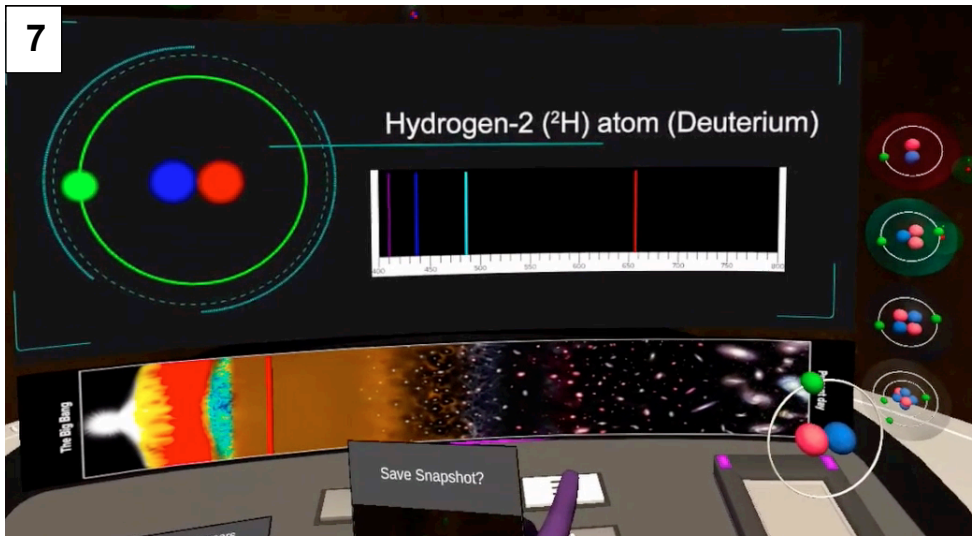

Lithium-7 (⁷Li) atom
Three protons, four neutrons, three electrons.
Atomic Number: 3
Mass Number: 7
Atomic Mass: 7.01600 amu
Net Charge: 0
Save Snapshot?

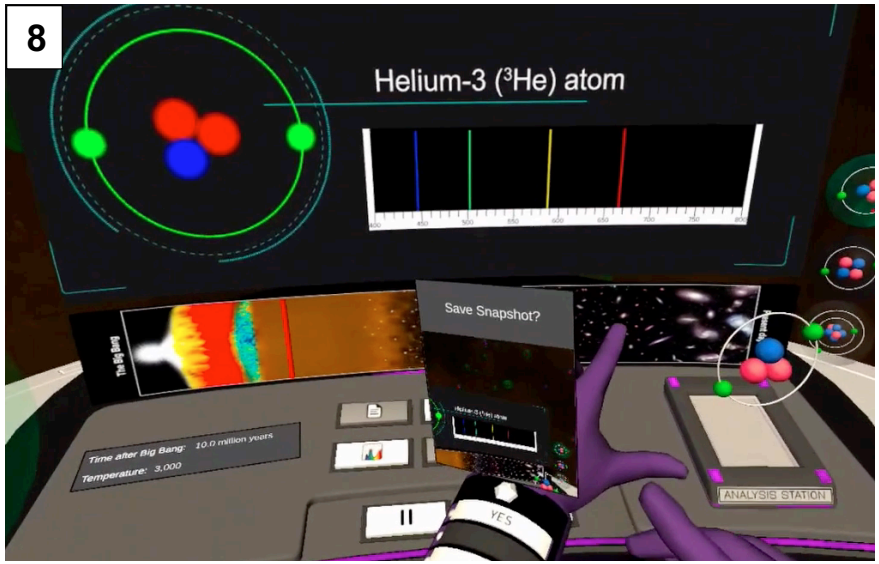
6


Hydrogen-1 (¹H) atom
Save Snapshot?

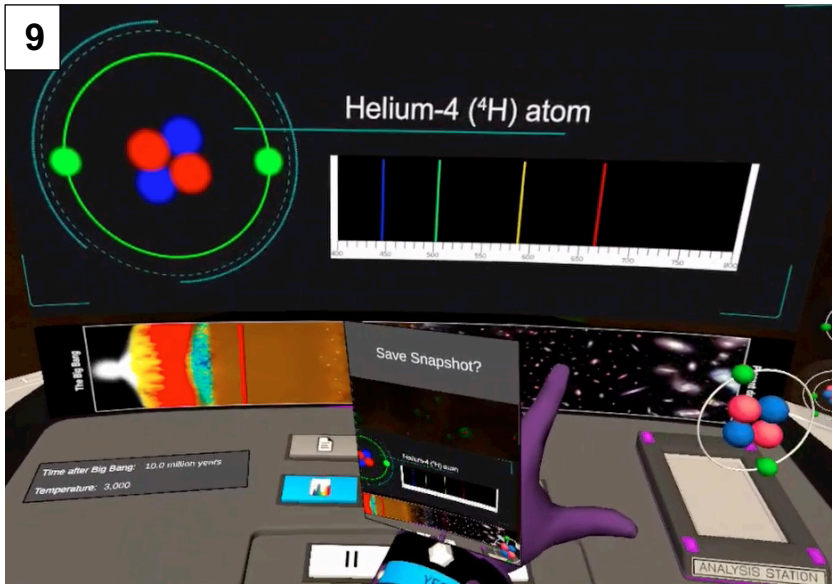
7


Hydrogen-2 (²H) atom (Deuterium)
Save Snapshot?

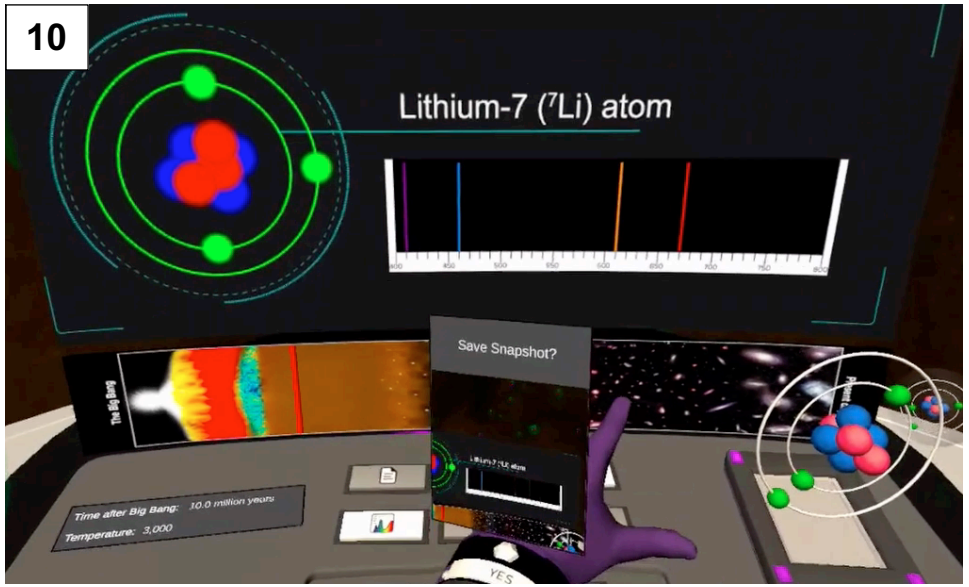
8


Helium-3 (³He) atom
Save Snapshot?
ANALYSIS STATION

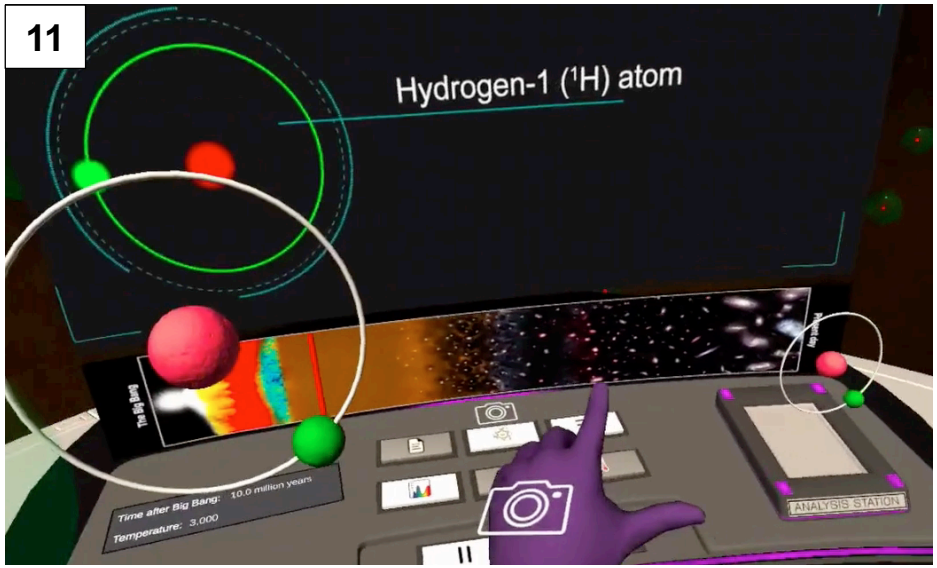
9


Helium-4 (⁴H) atom
Save Snapshot?
Time after Big Bang: 10.0 million years
Temperature: 3,000
ANALYSIS STATION

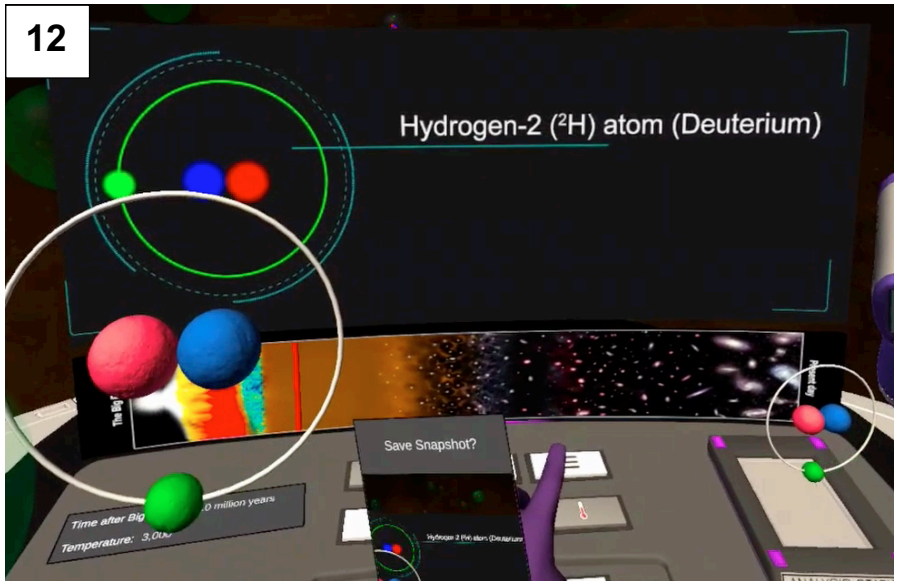
10


Lithium-7 (⁷Li) atom
Save Snapshot?
Time after Big Bang: 10.0 million years
Temperature: 3,000

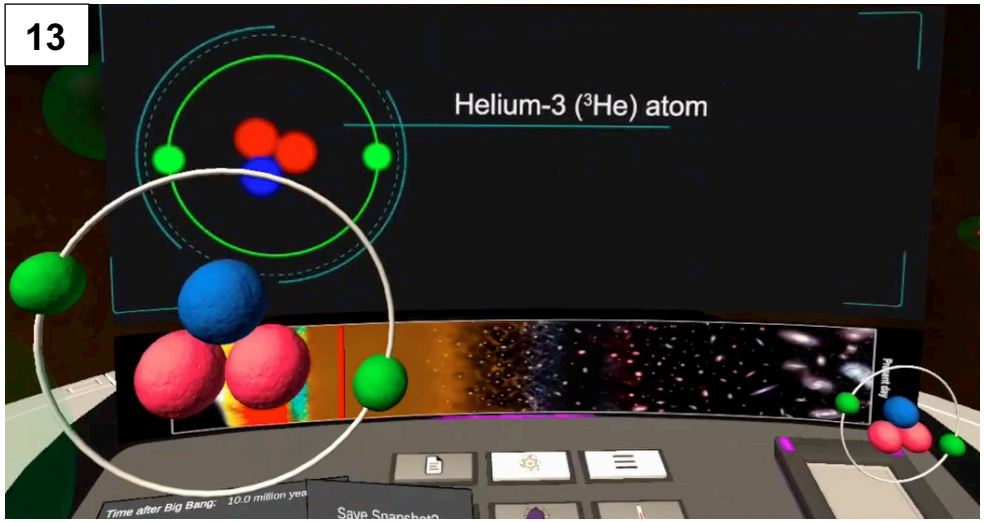
11


Hydrogen-1 (¹H) atom
Time after Big Bang: 10.0 million years
Temperature: 3,000
ANALYSIS STATION

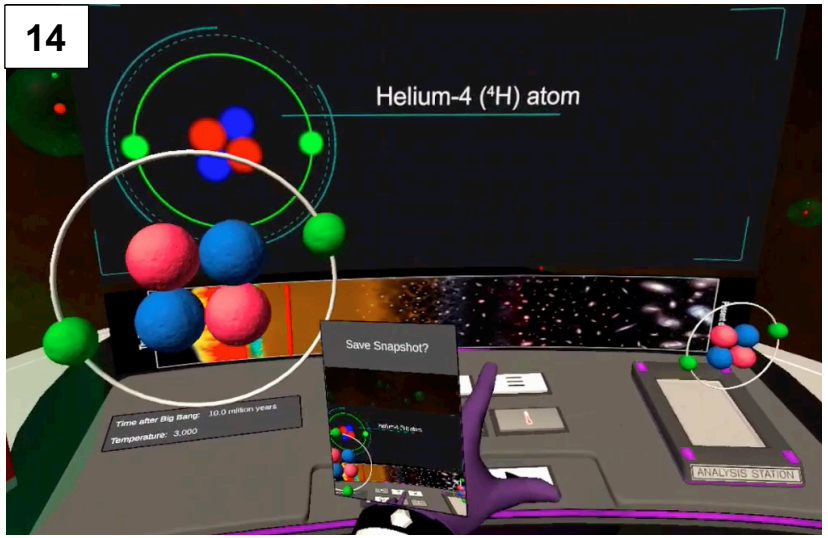
12


Hydrogen-2 (²H) atom (Deuterium)
Save Snapshot?
Temperature:

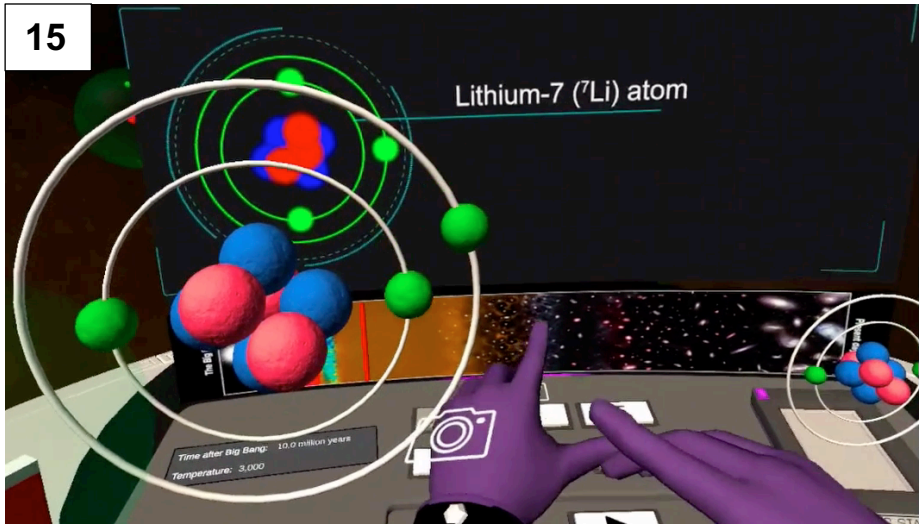
13


Helium-3 (³He) atom
Time after Big Bang: 10.0 million yea
Save Snapshot?

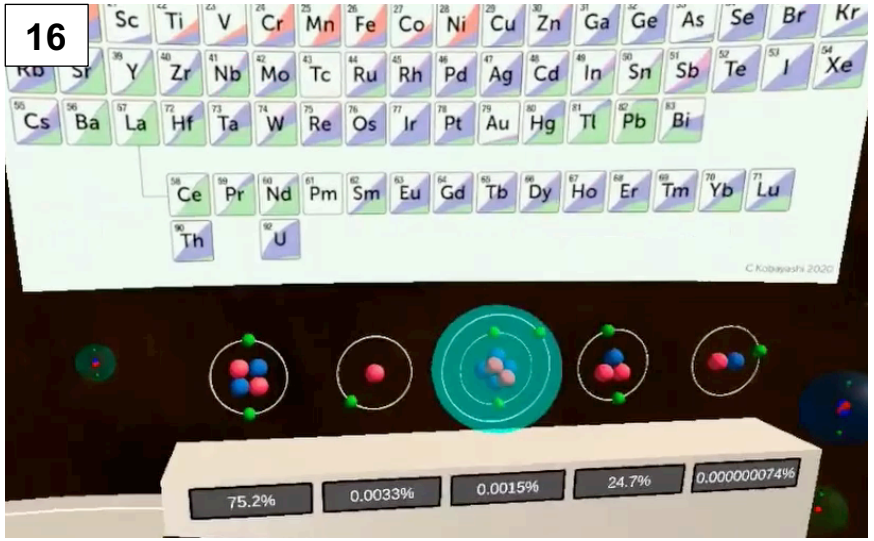
14


Helium-4 (⁴H) atom
Save Snapshot?
Time after Big Bang: 10.0 million years
Temperature: 3,000
ANALYSIS STATION

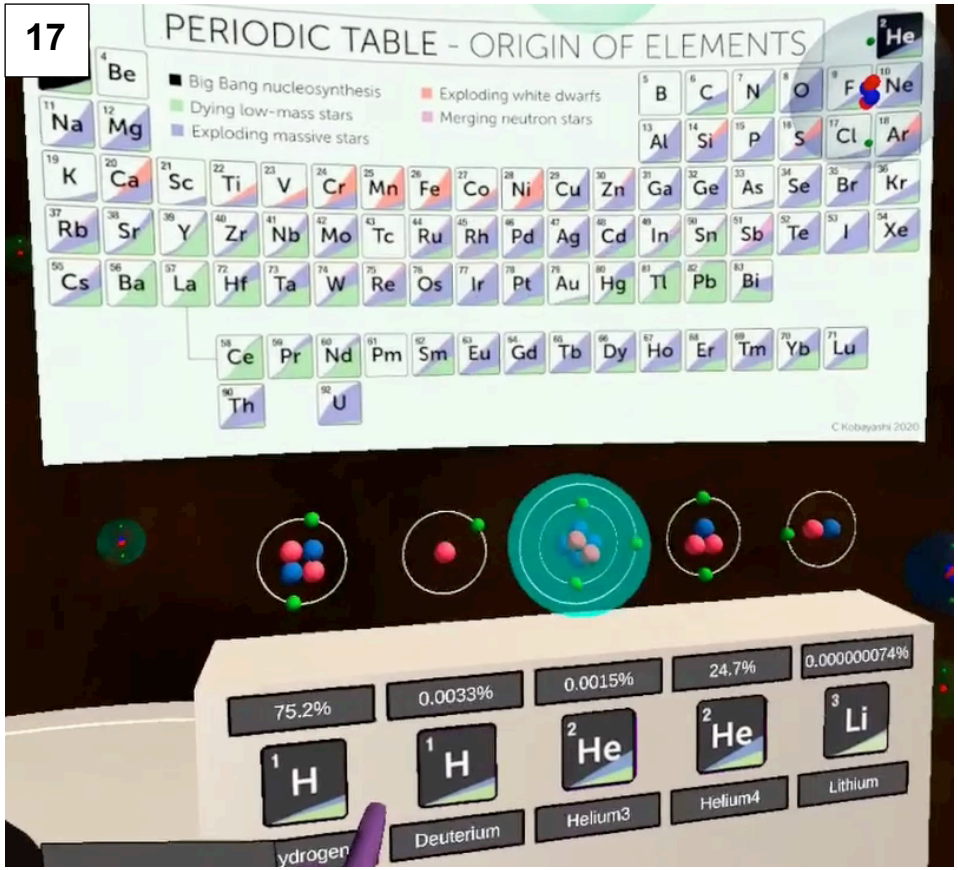
15


Lithium-7 (⁷Li) atom
Time after Big Bang: 10.0 million years
Temperature: 3,000

16


75.2%
0.0033%
0.0015%
24.7%
0.00000074%

17


PERIODIC TABLE - ORIGIN OF ELEMENTS
Big Bang nucleosynthesis
Dying low-mass stars
Exploding massive stars
Exploding white dwarfs
Merging neutron stars
C Kobayashi 2020
75.2%
0.0033%
0.0015%
24.7%
0.00000074%
H
H
He
He
Li
Deuterium
Helium3
Helium4
Lithium

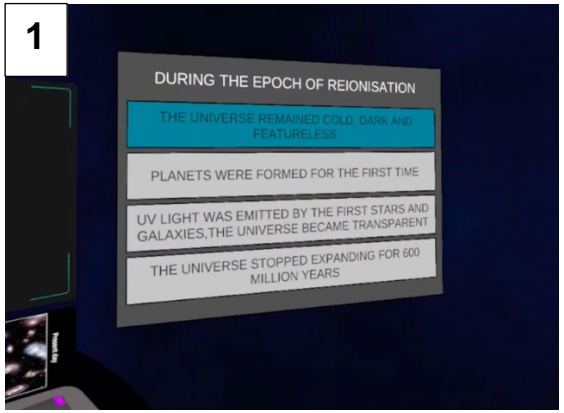
3. Epoch of Reionisation

Research task	Location for snapshot	#	Snapshot of what
	List of options on right of console. *During the Epoch of Reionisation:* *1) the Universe remained cold, dark and featureless.* *2) planets were formed for the first time.* *3) ultraviolet light was emitted by the first stars and galaxies and the Universe became transparent.* *4) the Universe stopped expanding for 600 million years.*	1	Selection of what happened during the EoR
		2	Revised selection of what happened during the EoR
Research Task 1: *1) Scan the smallest star.* *2) Use the appropriate buttons on your console to fill in the missing data about the star.* (#4, 5, 6 not necessarily in this order)	Monitor/console	3	First star #1 – info and model ***First star #1:*** *Radius: 4 $R_\odot$* *Luminosity: 1 million $L_\odot$* *Lifespan: 3 million years*
	Monitor/console	4	First star #1 – Composition info ***First star #1:*** *Composition: H, He*
	Monitor/console	5	First star #1 – Mass info ***First star #1:*** *Mass: 100 $M_\odot$*
	Monitor/console	6	First star #1 – Temperature info ***First star #1:*** *Temperature: 100,000 K*
Research Task 2: *1) Scan the largest star.* *2) Use the appropriate buttons on your console to fill in the missing data about the star.* (#8, 9, 10 not necessarily in this order)	Monitor/console	7	First star #2 – info and model ***First star #2:*** *Radius: 14 $R_\odot$* *Luminosity: 30 million $L_\odot$* *Lifespan: 3 million years*
	Monitor/console	8	First star #2 – Composition info ***First star #2:*** *Composition: H, He*
	Monitor/console	9	First star #2 – Mass info ***First star #2:*** *Mass: 1000 $M_\odot$*

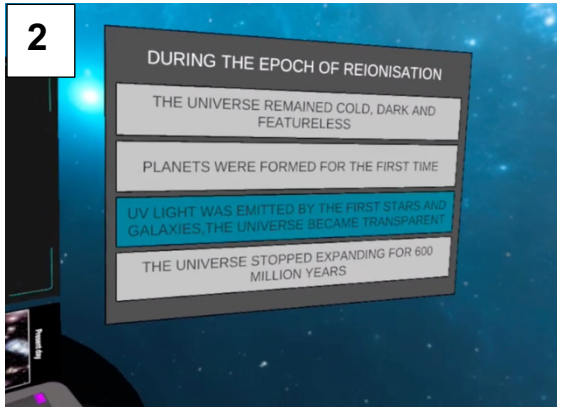
	Monitor/console	10	First star #2 – Temperature info ***First star #2:*** *Temperature: 110,000 K*
Research Task 3 *1) Scan the Sun* *2) Use the appropriate buttons on your console to fill in the missing data about the Sun.* (#12, 13, 14 not necessarily in this order)	Monitor/console	11	The Sun – info and model ***The Sun*** *Radius: 1 $R_\odot$* *Luminosity: 1 $L_\odot$* *Lifespan: 10 billion years*
	Monitor/console	12	The Sun – Composition info ***The Sun*** *Composition: H, He, O, C, Ne, Fe*
	Monitor/console	13	The Sun – Mass info ***The Sun*** *Mass: 1$M_\odot$*
	Monitor/console	14	The Sun – Temperature info ***The Sun*** *Temperature: 5,778 K*

EPOCH OF REIONISATION SNAPSHOTS

1



2



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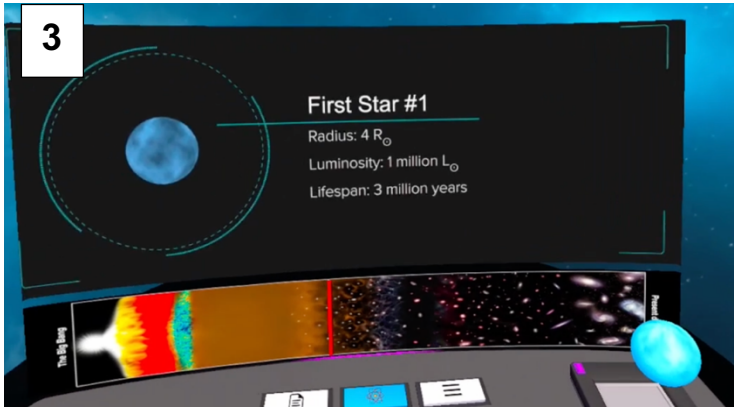
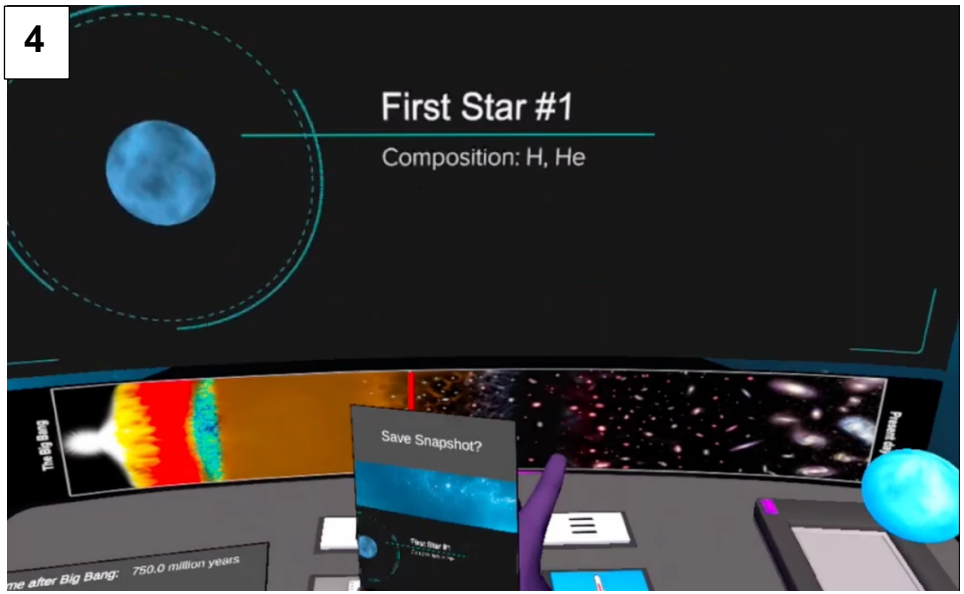


4



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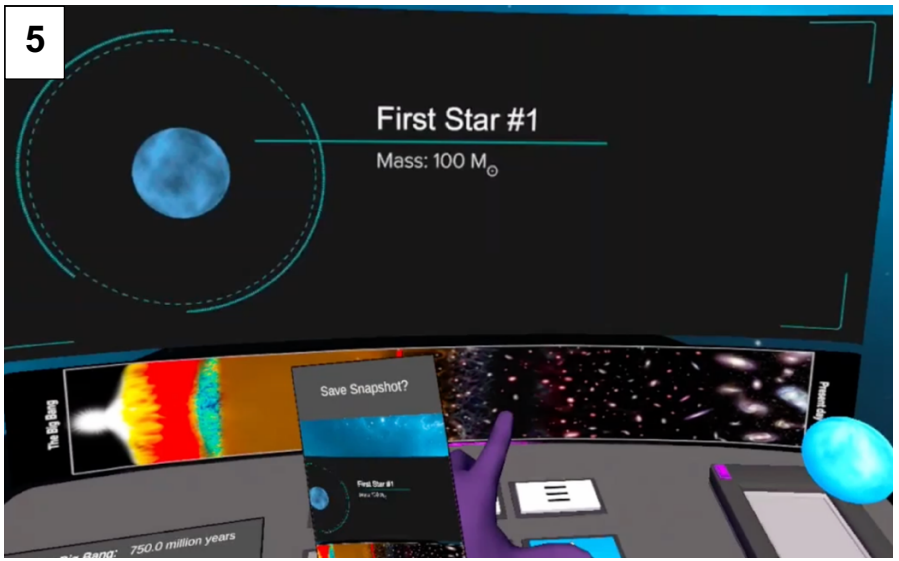
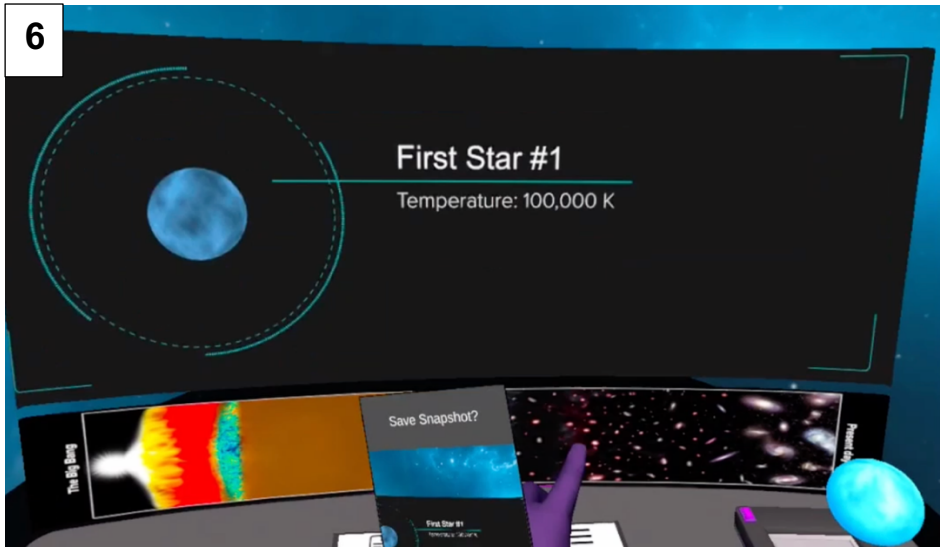
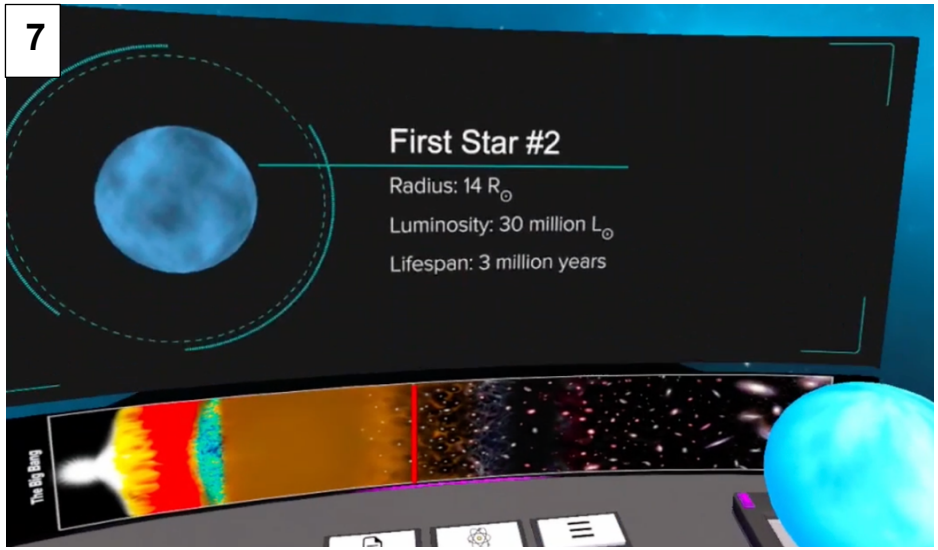


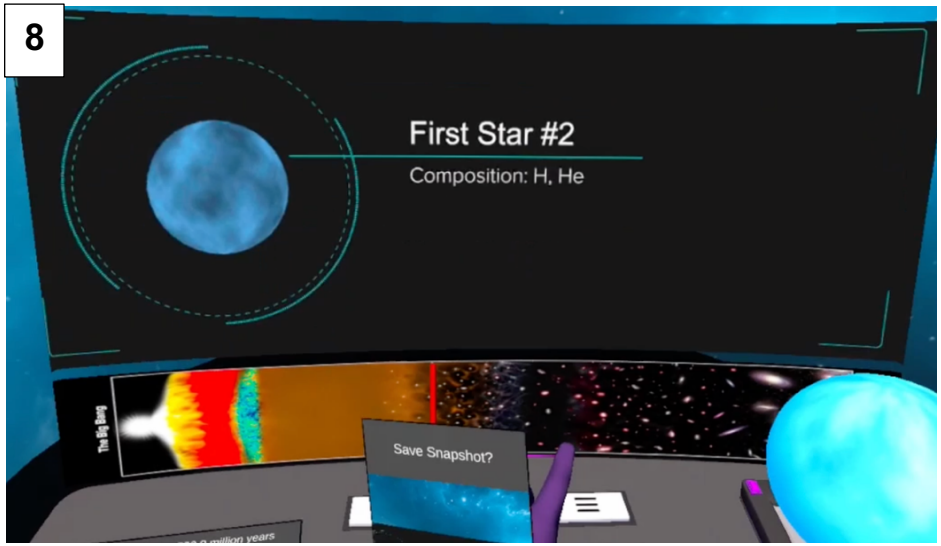
6


First Star #1
Temperature: 100,000 K
Save Snapshot?
The Big Bang

7


First Star #2
Radius: 14 $R_\odot$
Luminosity: 30 million $L_\odot$
Lifespan: 3 million years
The Big Bang

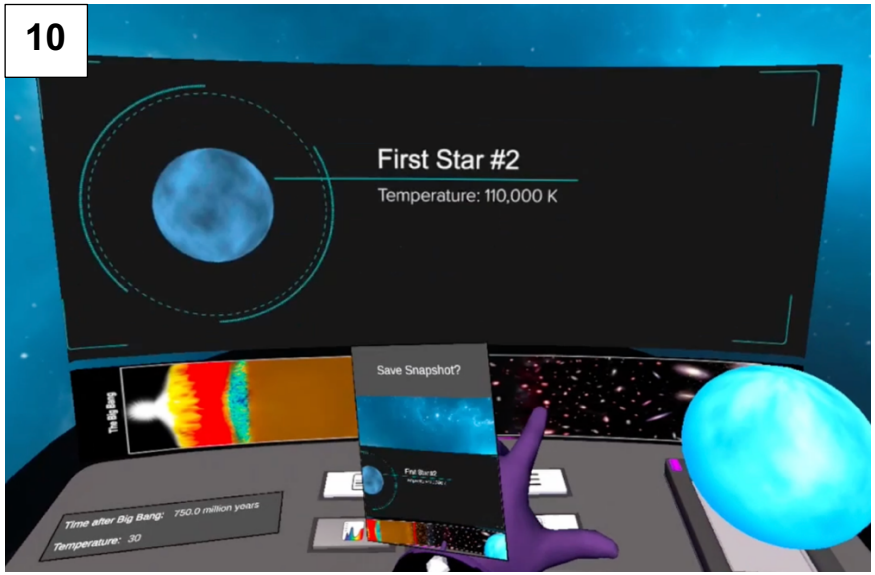
8


First Star #2
Composition: H, He
The Big Bang
Save Snapshot?

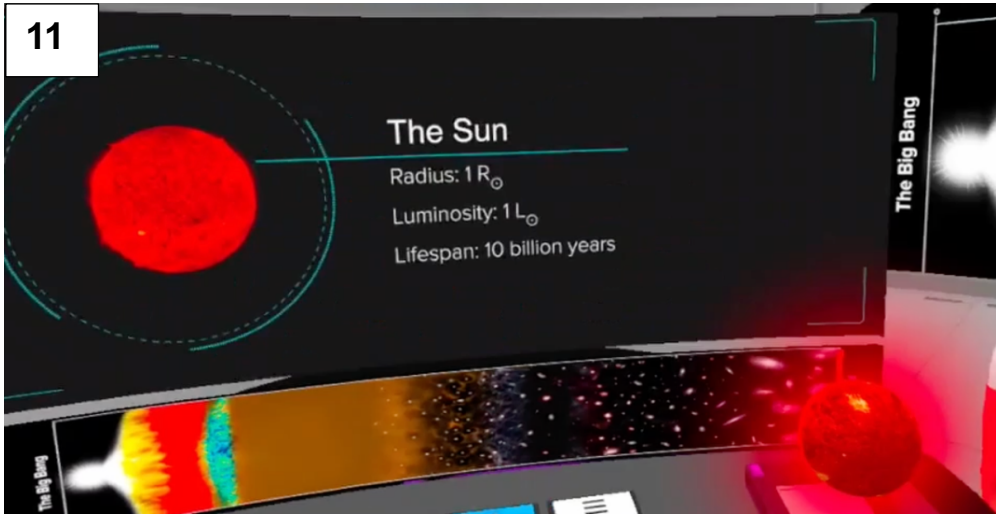
9


First Star #2
Mass: 1000 $M_\odot$
Save Snapshot?
The Big Bang

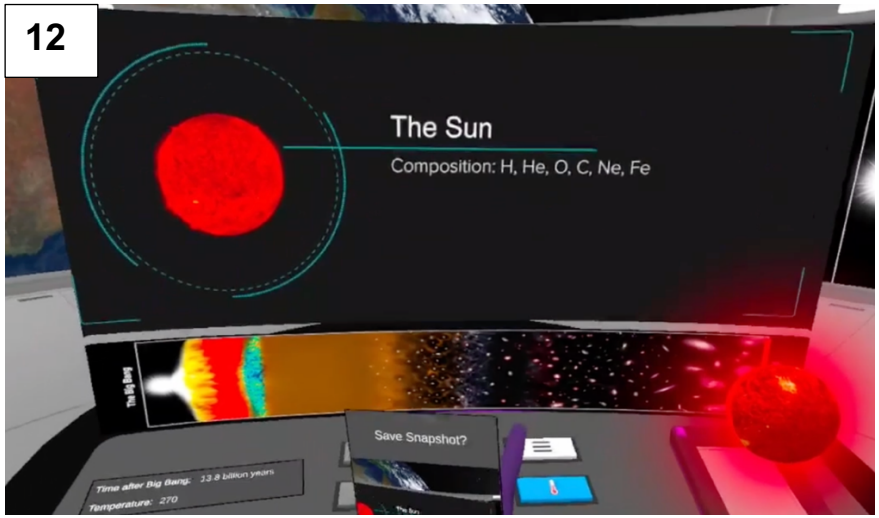
10


First Star #2
Temperature: 110,000 K
Save Snapshot?
Time after Big Bang: 750.0 million years
Temperature: 30

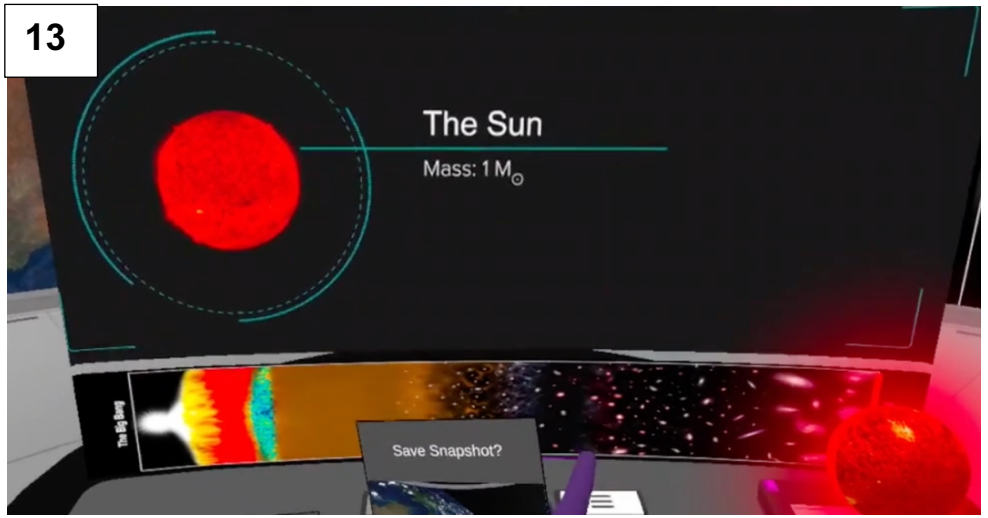
11


The Sun
Radius: 1 $R_\odot$
Luminosity: 1 $L_\odot$
Lifespan: 10 billion years
The Big Bang

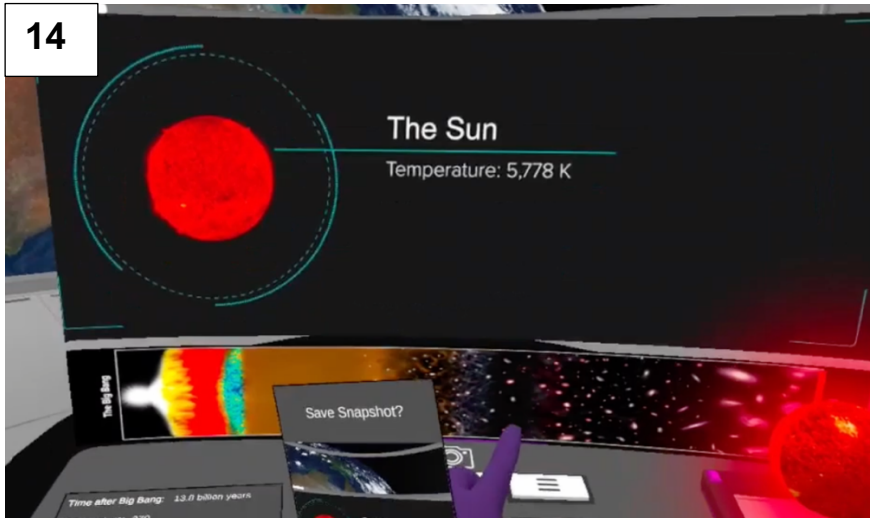
12


The Sun
Composition: H, He, O, C, Ne, Fe
Save Snapshot?
Time after Big Bang: 13.8 billion years
Temperature: 270

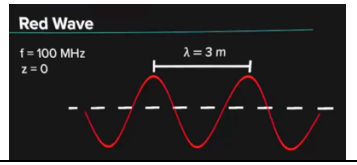
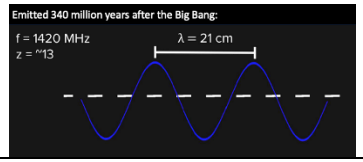
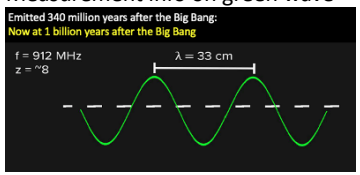
13

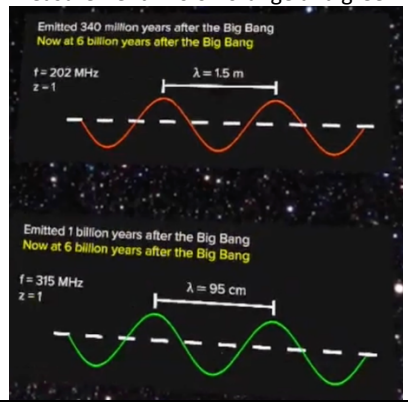
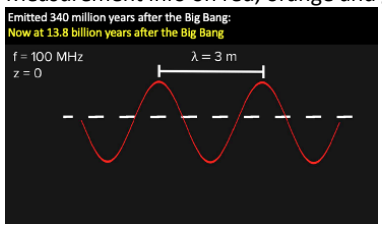
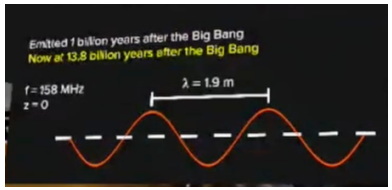
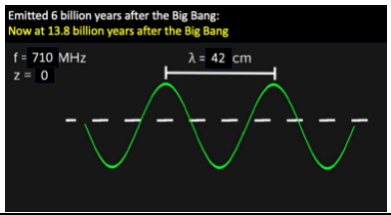

The Sun
Mass: 1 $M_\odot$
Save Snapshot?

14


The Sun
Temperature: 5,778 K
Save Snapshot?
Time after Big Bang: 13.8 billion years

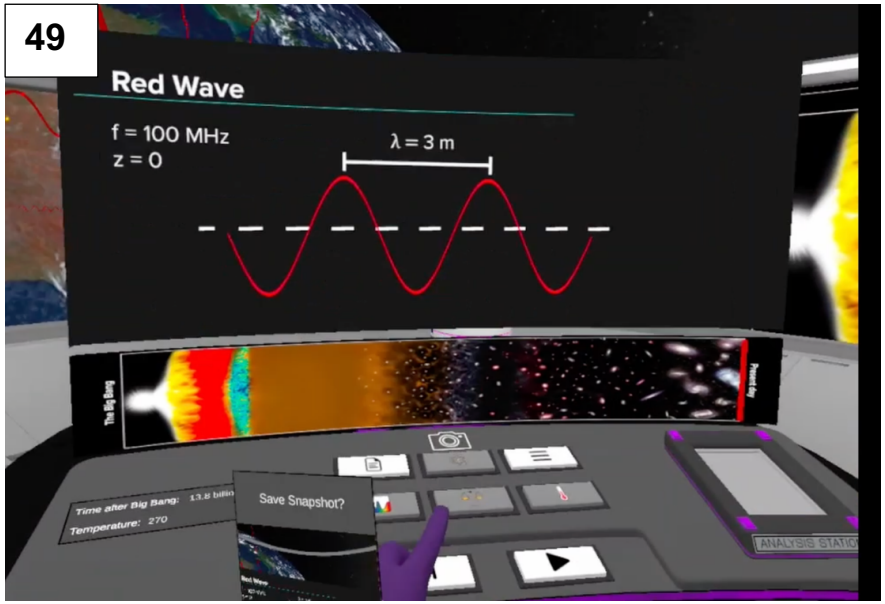
4. Signals from Cosmic Dawn

Research task	Location for snapshot	#	Snapshot of what
In this activity, except for Research Task 1 and the research questions, the research tasks only come up on the monitor if the user pushes the task button.			
Research Task 1 *Put on the Electromagnetic Spectrum visor* ***Research questions:*** 1. *What created the red wave?* 2. *Where did it originate?* 3. *How far has it travelled?* 4. *Has it changed over time?* 5. *If so, what caused this change?*			
Research Task 2 *Pause the waves.*			
Research Task 3 *Tune the radio (until you hear a low deep hum).*			
Research Task 4 *Measure the wavelength of the red wave, crest to crest*	Monitor/console	1	Measurement info on red wave 
Research Task 5 *Put on a spacesuit and select the 21cm line activity on the Universe timeline.*			
340 million years after the Big Bang ***Research Task 6*** *Use the [pause] button then scan a hydrogen atom.* *Measure the wavelength of the blue wave.*	To right of console	2	Measurement info on blue wave 
1 billion years after the Big Bang ***Research Task 7*** *1) Pause the wave.* *2) Measure the wavelength of the wave.*	To right of console	3	Measurement info on green wave 

6 billion years after the Big Bang ***Research Task 8*** *1) Pause the waves.* *2) Measure the wavelength of each wave.*	To right of console	4	Measurement info on orange and green waves 
Research Task 9 *Measure the wavelengths of each wave.*	To right of Kirsten in the Transporter Room	5	Measurement info on red, orange and green waves   
Research questions: 2. *What created the red wave?* 3. *Where did it originate?* 4. *How far has it travelled?* 5. *Has it changed over time?* 6. *If so, what caused this change?*			

SIGNALS FROM COSMIC DAWN SNAPSHOTS

49



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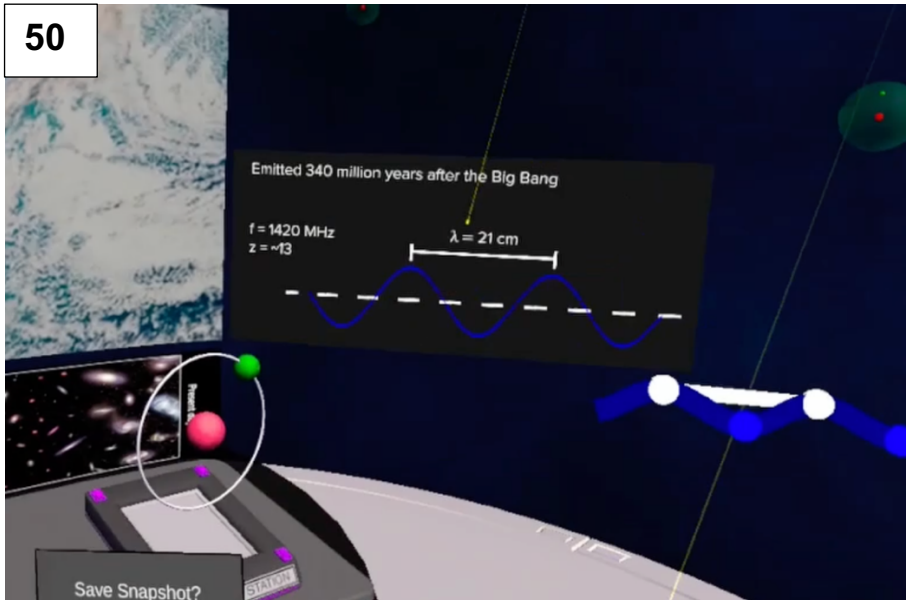

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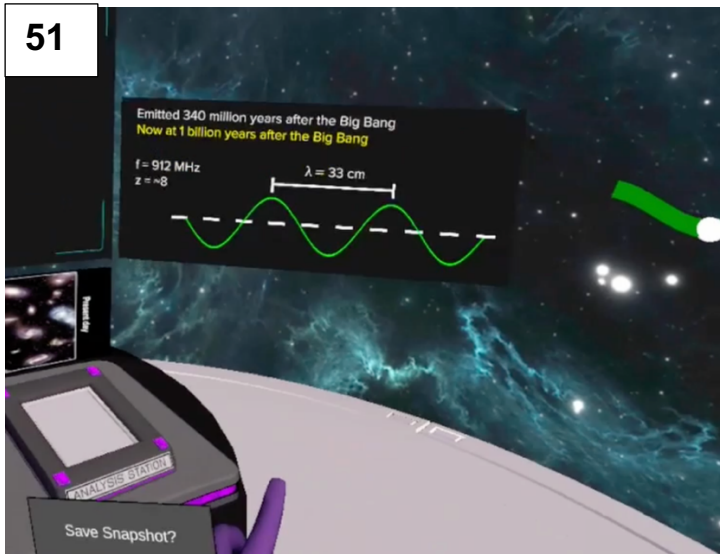

52