SCRIPTS/NARRATION
'Unlocking the Universe in 3D' Virtual Reality program

1. AVATAR DR KIRSTEN BANKS SCRIPT

Induction session 1 – basic training

Hi there, I'm astrophysicist Dr Kirsten Banks. Welcome to the Universe 3D Space Telescope, otherwise known as U3D. U3D is the first habitable space telescope orbiting the Earth… as you can see by looking outside. You have entered the U3D transporter room – the research hub of U3D. From where you're standing, take a moment to simply look around you.

Each time you come to U3D from Earth to start a new research task, you will arrive in the transporter room. From here, you will 'jump' into your work. And I mean literally 'jump'! But more on that soon.

You must complete some initial training to become familiar with the transporter room and the tools and devices that will help you in your research. It's essential to know how everything works before you start.

Let me introduce you to your console – the powerhouse for your research. It includes an instrument panel and a monitor. The instrument panel has all the measurement tools and devices needed for your research. The monitor will provide information and feedback on your tasks.

There's a bit to learn, so we will do it over two induction sessions.

For this first session, see the induction checklist on the monitor. Follow the instructions carefully.

Let's begin by learning how to move around the transporter room. Move to different points in the room to practise your new skill, then return to the console.

This is the U3D Universe timeline. It illustrates our latest understanding of the evolution of the Universe from the Big Bang to the present, spanning 13.8 billion years. This timeline is not just a fancy mural; it is your portal to significant points in time and space. For each research task, you will select a specific point to enter the Universe timeline. Point a controller directly at the timeline and hold down the side trigger. Scan the length of the timeline for some interesting facts. Return to the console when you are finished.

Wow! That spacesuit really suits you. Check out your reflection in the mirror.

You need a spacesuit to go out into space, right? You cannot teleport into the Universe timeline without first putting a U3D space suit on. When you return to the Transporter Room after each research task, you must return the suit to its cabinet. You just repeat the action with your controller. So do that now.

Take a closer look at the U3D wristband on your left wrist. They're the latest U3D issue. Return to the console to check your induction instructions on using the band.

That's enough for our first induction session. When you return for the second session, you will learn to use the tools on the console.

You are welcome to stay and explore the Transporter Room further. You can try on your space suit again, read more about the Universe timeline, and take some photos before returning to Earth. When ready, use your wristband's 'Return to Earth' function. I'll see you next time.

Induction session 2 – console training

Hi, welcome back to the Transporter room for session 2 of your induction. You are now familiar with teleporting around the room, the Universe timeline, your space suit, and your wristband. Let’s familiarise you with the tools you will use in your research.

On your console, there are various buttons, a gauge and an analysis station. You will use these tools and devices in your research tasks. They are integrated into a single platform with a wireless, hand-held scanner for ease of use. You use the scanner to select objects, take measurements and gather information. Grab the scanner by pressing the side trigger on your controller. It will emit a straight ray when you press the front trigger.

I’ve set up a practice session to familiarise you with how the console and measurement tools work.

Three models of space objects will appear in turn on the left side of the monitor. Use the scanner to select a space object and then press each highlighted button to get data and information on the object. Remember to take snapshots of the results. By looking at the various properties of the objects, can you work out what they are and what their names are?

Congratulations, your induction training is complete. You are now a full member of the U3D Space Telescope crew.

Before starting your research tasks, you will require further briefing from your research coordinator on Earth. I look forward to working with you when you return to U3D. Bye for now.

1. The oldest light

Hi there, this is Kirsten beaming in from U3D. I hope you can see my video feed clearly despite you being around 13.8 billion years back in time. Check out where you are on the timeline on your console. You have also shrunk to the size of a cell to explore atoms and sub-atomic particles. So cool!

You have arrived seconds after the Big Bang, and the young Universe is scorchingly hot. Still, as it rapidly expands, it is cooling. At an atomic level, things are changing really fast. It is your job to find out why. But first, just look around you and observe the state of the 'baby' Universe. What do you see?

To get an overview of the period you are researching, you and your console will now journey to 380,000 years after the Big Bang—'blink of an eye' considering the age of the Universe. This will take you only 30 seconds. Take a good look around as you travel through time. You will then come back to where you are now, and you'll be able to repeat the journey at your own pace so you can complete your research tasks. Push the play button to begin.

Now, to your research… You need to identify and collect evidence that supports the most widely accepted scientific model for the origin and evolution of the Universe – the Big Bang Theory. Don't forget to take snapshots of your results to complete your data collection. Good luck!

Well done, you have made it through the first 20 minutes or so of the Universe and observed the formation of the first nuclei. Scientists predict that at that time, something exciting occurred – the temperature and density of the Universe fell to the point where nuclear fusion couldn't continue.

What do you think happened then? Use the fast-forward button on your console to travel forward in time and see how far you and your console get before you stop. Remember to look around you and make observations as you travel.

OK, you are now 380,000 years after the Big Bang – a critical moment in the evolution of the Universe. Not much happened between 20 minutes and 380,000 years, despite the Universe continuing to cool and expand. Elemental abundances were nearly fixed, and the only changes resulted from the radioactive decay of the two major unstable products of the Big Bang Nucleosynthesis, tritium and beryllium-7. But then, something did happen that really excites cosmologists. Did you see that flash of orange light at the end? What caused it, and where did it go?

Well, that light continues to travel through the Universe and is, in fact, the oldest light that astronomers can observe. But how? I'll show you, but you have one more research task to complete. Return to the transporter room when you are finished.

Hi, welcome back.

Grab and put on the Electromagnetic Spectrum visor from the bench on your left. It will click into place.

What's the story behind all these colours outside U3D? Well, the light you saw emitted 13 billion years ago now looks like this. The photons continue to travel through the expanding Universe, making up the oldest light we can observe. Wherever you go in the observable Universe, this radiation exists …but as microwaves. It is called the Cosmic Microwave Background.

Why are there different colours? Point your scanner at the red and select the most appropriate button on your console to work that out. Then try scanning the dark blue. Remember to take snapshots of the results.

Well done! You have lots of data to work on back on Earth. How was it seeing the oldest light? It's time to return your space suit to the cabinet and return to Earth. See you the next time in U3D.

2. Exploring the first atoms in the Cosmic Dark Ages

Hi there! Welcome to what astronomers call the Cosmic Dark Ages. Check where you are on the timeline on your console. You are at around 10 million years after the Big Bang, but this era in the early Universe lasted around 150 million years, with very little happening during that time.

However, the Universe continued to expand and cool from around 3,000 Kelvin down to about 60 Kelvin (that's 3727 °C to about −213 °C). The Universe was smooth and featureless, devoid of light, any matter was diffuse, energy levels were low, and at an atomic level (where you are now), it was a cold, dark fog of mostly neutral hydrogen and helium atoms with a couple of other stable isotopes. The atomic gas absorbed any short-wavelength radiation that may have been emitted.

So, you can see why we call it the 'Dark Ages'!

You have some research tasks to complete here to find out about the atomic structure of some of the first atoms.

Don’t forget to take snapshots of your work to add to your data collection. I’ll come back when you’re done. Good luck!

Hey, great job! It's time to return to the Transporter Room, remove your space suit and then return to Earth to analyse your results. You have lots to follow up on. Bye!

3. Epoch of Reionisation

Hello again! This research task is really exciting.

You have arrived at the start of the next crucial period in the evolution of the Universe. Check where you are on the console timeline.

Astronomers call this period the Epoch of Reionisation, and peering into this time is both a challenge and a quest for those astronomers. Modelling suggests that it lasted around 600 million years. So, what happened to the Universe during that time and why is it so crucial to our understanding of its evolution? Scan your best guess from the four options on your right.

OK, let’s see if your selection matches our current understanding. You will now take an accelerated journey through a supercomputer simulation of the Epoch of Reionisation - a 600-million-year voyage in just over two minutes. Enjoy your front-row seat! Remember to take a good look around you.

Push play when you are ready.

Wasn’t that just awesome? Let’s do it again; this time, you will get a guided tour of what you see. Push play to begin.

Now you have more information, let’s revisit those four options I gave you on the Epoch of Reionisation. Scan your answer again, even if it hasn’t changed.

The first stars played a significant role in the transformation of the Universe during the Epoch of Reionisation, and the U3D team is keen to learn more about them and how they compare to the star we know most – our Sun.

For your research tasks, you will collect some data on the first stars and then return to the Transporter Room to analyse our Sun. Good luck!

Welcome back to U3D. Complete your research task on the Sun, return your space suit to the cabinet and then return to Earth to analyse your results. I’ll see you for your next research adventure. Bye!

4. Signals from Cosmic Dawn

Hi, welcome back to U3D. Are you ready to embark on your next exciting research adventure?

Press the play button to watch a brief video. This will hint at what this research task is about.

Radio astronomy extends our view further into the Universe's history than optical telescopes. With their longer wavelength, radio waves can pass through many materials that would otherwise block or absorb other forms of electromagnetic radiation, such as visible light.

You'll use the tools – the Electromagnetic Spectrum visor, the FM radio and the scanner – to see, hear and measure a particular radio wave – a persistent signal that has been travelling through the Universe for 12 billion years and one that is of particular interest to Australian radio astronomers.

You will do the first part of your research task here in the Transporter Room before teleporting to around 340 million years after the Big Bang to conduct part 2 of your research.

There are a few steps to Part 1, so I will talk you through them. So… let's get started.

Put on your Electromagnetic Spectrum visor.

The visor has been pre-programmed to enable you to view radio waves. The waves you see all around you have been emitted by objects and events from the vast expanses of space, and these radio waves are important to radio astronomers.

Take a look around. Teleport over to the U3D windows and look down to Earth. Come back to the console when you are done.

Now, pause the waves.

You need to single out a particular radio wave to start your research task. Use the FM radio to scan and 'tune in' to the desired frequency or channel. You'll need to use your ears and your eyes. When you have found it, stop.

Hmm, these red waves are obviously significant. On the monitor are five questions.

To complete your research task, you must answer them with the information you collect.

Use your scanner to measure the wavelength of the red wave – crest to crest or, if you prefer, trough to trough.

Wow! 3 metres. That's quite a long wavelength!

On your monitor, you will see three pieces of information about the red radio wave as we see it in the Transporter Room today. You'll need to go back in time to answer the questions, so put on your space suit and select the 'Signals from Cosmic Dawn' point on the Universe timeline. I'll meet you there!

Welcome back to the Epoch of Reionisation. The last time you were here, it was at astronomical size.

This time, however, you are at atomic size and surrounded by neutral hydrogen atoms. Lots and lots of them, as, after all, they made up around 75% of the baryonic matter in the Universe at this time.

Observe what's happening around you for a few seconds. What is being emitted by some of the atoms?

Now, pause the Universe and select a hydrogen atom.

Observe what's happening to the model on the analysis station.

The electron is emitting a photon at a particular wavelength. Measure the wavelength.

Let's follow this wave as it travels through the Universe. Your console will automatically teleport you to three different points in the Universe's history where you can see this wave and measure its wavelength. Do you think it will change?

Also, at each stop, you will pick up another photon emitted at 21 cm from the model of a neutral hydrogen atom. Ensure you take wavelength measurements of each emission line and check where you are on the Universe timeline. I'll see you back at U3D when you are done.

Welcome back to the present – 13.8 billion years after the Big Bang. You have three waves to measure. Do that now.

So, you've seen a model of a hydrogen atom emit a radio wave at 21cm three times – at 340 million years, 1 billion years and 6 billion years after the Big Bang. You have observed changes in the wavelengths, taken measurements and gathered data at each stop. When you return to Earth, use this information to address the research questions.

It's time to take off your spacesuit and head back to Earth. Bye!

2. KIRSTEN'S NOTES

Kirsten notes are accessed via the 'Kirsten's notes' button on the console. These provide extra information for users.

Console training

(For Proxima Centauri)

What am I?

This red dwarf star is our nearest neighbour, lying only 4.25 light-years away. It emits far less energy than the Sun and glows too dimly for us to see it from Earth with the naked eye. In 2016, an exoplanet was discovered orbiting the star.

(For oxygen atom)

What am I?

This chemical element is the most abundant element in the Earth's crust. It is pale blue in solid or liquid form.

(For Andromeda)

What am I?

This large, bright neighbouring galaxy is hurtling towards the Milky Way at ~140 km/sec. Luckily, it is 2.45 million light-years away.

The Oldest Light

Big Bang Nucleosynthesis

BBN refers to the process by which light elements (such as hydrogen, helium, and traces of lithium and beryllium) were formed in the early Universe during the first few minutes after the Big Bang. As the Universe expanded and cooled, protons and neutrons began to combine to form these elements through nuclear fusion. The exact abundances of these elements depend on the density of matter and radiation in the early Universe and the rate at which the Universe was expanding. This process is considered one of the key pieces of evidence supporting the Big Bang model of the Universe.

Cosmic Microwave Background

The Cosmic Microwave Background (CMB) is a faint, uniform glow of radiation that fills the entire observable Universe. It's a remnant of the Big Bang and crucial evidence for this theory. As the Universe expanded and cooled, particles combined to form atoms, allowing photons to travel freely for the first time. This light has been traveling through space ever since, offering a snapshot of the early Universe.

The CMB's temperature is nearly uniform in all directions, but small variations known as 'anisotropies' are used to study matter distribution. Studying the CMB helps astronomers understand the Universe's history, age, composition, and shape.

ASTRO 3D

Exploring the first atoms in the Cosmic Dark Ages

What determines the properties of an atom?

Atoms have several key properties that define their behaviour and interactions. The number of protons defines the element and determines its chemical properties. The variation in the number of neutrons influences an isotope's atomic mass, stability, and nuclear properties.

Atomic mass is the total weight of an atom and is typically measured in atomic mass units (AMU). The mass of an atom is primarily determined by the sum of its protons and neutrons. Electrons are much lighter and contribute only a tiny fraction to the overall mass.

What is an isotope?

Isotopes are variants of a chemical element. They have the same number of protons but a different number of neutrons in their atomic nuclei. The variation in neutron count gives rise to different isotopes of an element.

During the Cosmic Dark Ages, only stable isotopes of three atoms existed. Hydrogen had two isotopes – protium (no neutrons, most abundant) and deuterium (one neutron, rare). Helium had helium-3 and helium-4 (highly stable, dominant isotope produced during the Big Bang nucleosynthesis).

Isotopic variations of chemical elements are used in fields ranging from radiocarbon dating to nuclear physics and medicine.

Epoch of Reionisation

Strömgren Sphere.

In theoretical astrophysics, a Strömgren sphere is a region of space around a central, hot, massive star where the star's intense ultraviolet radiation creates an ionisation front pushing out into the neutral interstellar medium. This creates a spherical 'bubble' of ionised hydrogen around the star. The size of the Strömgren sphere depends on the star's brightness and the density of the surrounding gas.

Can we see the first stars?

Directly observing the very first stars remains a significant challenge. These stars lived and died over 13 billion years ago, and their light has had to travel vast distances across an expanding universe. While we can't see the first stars individually, astronomers have indirect evidence of their existence through the chemical composition of later-generation stars and the ionisation effects on the primordial gas. Advanced telescopes and gravitational lensing may provide opportunities to glimpse these ancient stars in the future, but direct observation remains elusive at present.

Signals from Cosmic Dawn

The SKAO-Low Telescope

The telescope will be hosted at Inyarrimanha Ilgari Bundara (the Murchison Radio-astronomy Observatory) in a remote, radio-quiet region in Western Australia.

The SKAO antennas are made of horizontal branches called dipoles. The smallest dipole is at the top, graduating to the largest at the bottom. The larger the dipole, the longer the wavelength it absorbs. The longer the wavelength the lower the frequency.

The thousands of antennas will form an interferometer, scanning the sky for 50-350 MHz frequencies. The 400,000m^2 collecting area will enable astronomers to produce images with 10-100 times the resolution of current telescopes, detecting fainter and farther objects.

Ref: https://www.skao.int/en/explore/telescopes/ska-low

The spin-flip transition

As quantum mechanical particles, the proton and electron in a hydrogen atom have a property called 'spin'. The particles act as if they are spinning on their axes. In their lowest energy state, the proton and electron spin in opposite directions. When an electron acquires a small amount of energy due to collisions with other particles, its 'spin state' changes to match the proton's. The spin-flip transition occurs when (after around 10 million years!) the electron flips its spin orientation back to its lower energy state, and a packet of energy (a photon) is emitted at a wavelength of 21cm. This phenomenon can only be used to observe the presence of neutral hydrogen in the Universe.

Ref: https://astronomy.swin.edu.au/cosmos/S/Spin-flip+Transition

3. NARRATION IN THE EPOCH OF REIONISATION COMPUTER SIMULATION FLYTHROUGH

You are entering the Universe at around 340 million years after the Big Bang. For millions of years, it has been cold, dark and featureless, but a transformation is beginning. The massive black clouds of dense, neutral hydrogen that make up the Universe are slowly dissipating, revealing blue, illuminated spaces. The Universe resembles a cosmic sponge.

You'll begin to see tiny, brilliant points of light emerging. You are witnessing the birth of the first luminous objects in the Universe: Population III stars. These massive, short-lived stars - mostly hydrogen and helium - begin to shine their intense ultraviolet radiation, illuminating their surroundings like cosmic beacons.

The first galaxies begin to form, composed of not only Population III stars but also less massive Population II stars, as well as supermassive black holes at their centres. The cumulative radiation from these cosmic objects is powerful enough to strip electrons from the surrounding neutral hydrogen atoms, ionising them into charged particles.

The blue translucent regions are the vast, brilliantly lit bubbles of ionised gas expanding around the galaxies and into each other. This is led by the ionisation fronts represented in white. Everything is interconnected by long, dark filaments of neutral hydrogen. The Universe becomes an intricate web of ionized and neutral regions.

Slowly, over millions of years, the ionised transparent regions become so vast only isolated islands of hydrogen cloud remain.

Your journey ends approximately 1 billion years after the Big Bang. The majority of the Universe was reionised, and light across much of the electromagnetic spectrum could travel unobstructed through the cosmos, eventually revealing the Universe as we see it today.

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