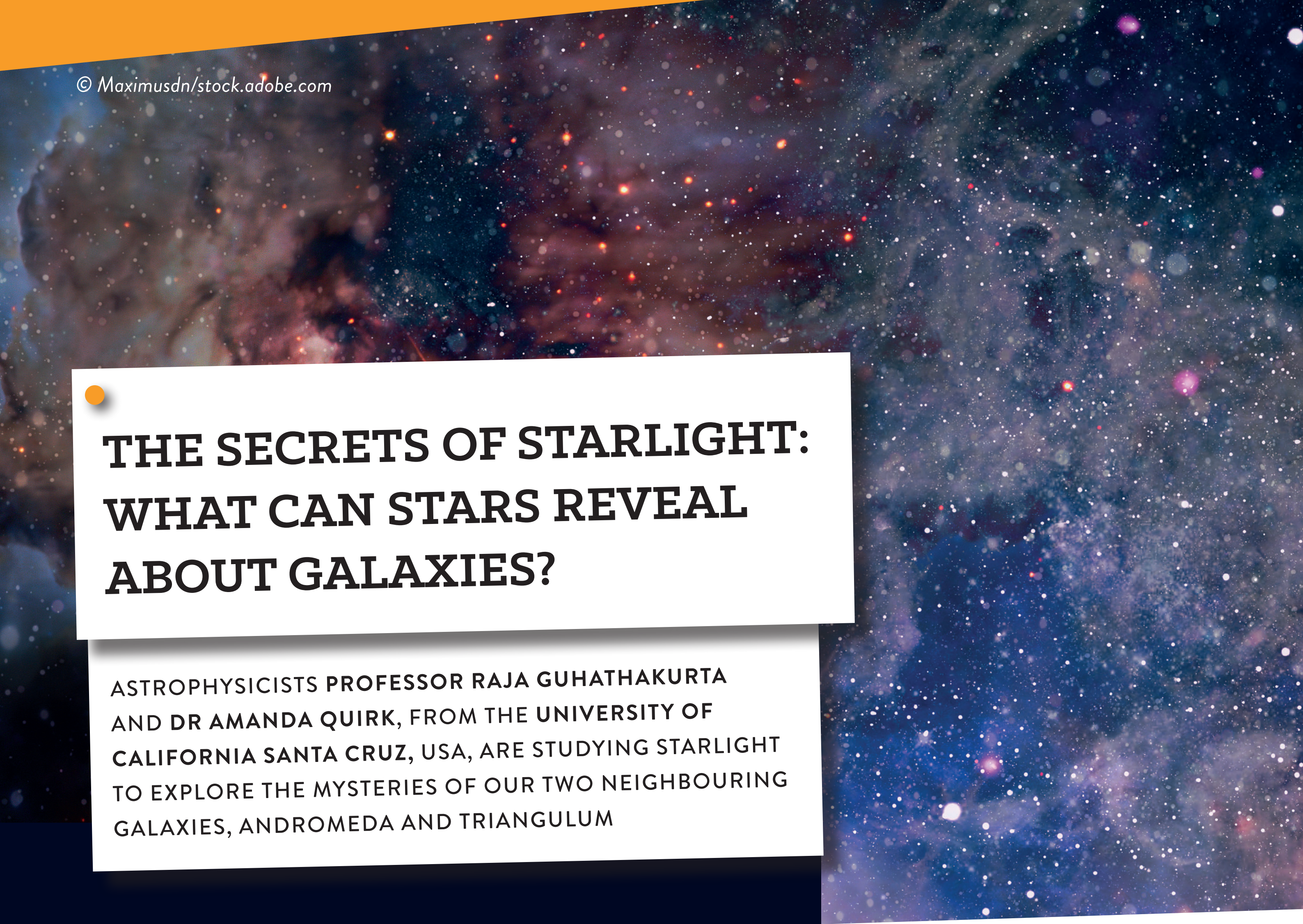

THE SECRETS OF STARLIGHT: WHAT CAN STARS REVEAL ABOUT GALAXIES?

ASTROPHYSICISTS **PROFESSOR RAJA GUHATHAKURTA** AND **DR AMANDA QUIRK**, FROM THE **UNIVERSITY OF CALIFORNIA SANTA CRUZ**, USA, ARE STUDYING STARLIGHT TO EXPLORE THE MYSTERIES OF OUR TWO NEIGHBOURING GALAXIES, ANDROMEDA AND TRIANGULUM

TALK LIKE AN ASTROPHYSICIST

GALAXY – a very large collection of gas, dust, billions of stars and planets, and a mysterious substance called dark matter held together by gravity

HUBBLE SPACE TELESCOPE – a space-based astronomical telescope that orbits ~500 km above Earth

LIGHT-YEAR – the distance travelled by light in one year (equal to ~9,000,000,000,000 km)

SPECTROSCOPY – the study of the wavelengths of light from a star

SUPERNOVA – the explosion of a star

WAVELENGTH – the distance between the crests of a light wave, a property we perceive as colour

Professor Raja GuhaThakurta and Dr Amanda Quirk are galactic explorers. From their base at the University of California Santa Cruz, USA, planet Earth, these two astrophysicists study the light released millions of years ago from the Andromeda and Triangulum galaxies. While you might call them stars of science, they would tell you that, in a way, every one of us is a star.

HOW ARE WE MADE OF STARDUST?

More than 96% of your body is made up of just four elements: hydrogen, oxygen, carbon and nitrogen. At the start of the Universe, however, only the simplest of these – hydrogen – existed. All other elements that are essential for life were created within stars.

The centre of a star is a nuclear reactor, where the atoms of lighter elements are fused together to create heavier ones like oxygen and carbon. This reaction releases huge amounts of energy, which is why stars radiate so much heat and light. This energy also stops stars collapsing in on themselves under the pressure of gravity.

However, when a massive star eventually runs out of fuel to power its nuclear reactor, there is nothing left to hold gravity back, and the core of the star implodes. The subsequent bounce causes an almighty blast that sends the heavy elements out into space. Known as a supernova, this is how stardust is created. In a galaxy, gravity causes the stardust created by generations of supernovae to clump together, forming new stars and planets. This is how our own solar system and planet were created. So, were it not for the dust of ancient exploded stars, there would be no such thing as life as we know it.

WHY STUDY OTHER GALAXIES?

We live in a galaxy – the Milky Way – so it may seem odd that Raja and Amanda are more interested in Andromeda and Triangulum, both of which are over 2.5 million light years away. However, it is hard to view a galaxy from inside it.

Imagine you want to take a photo of your school. To get a good view, you would need to stand outside the building. Would this be practical if your school was as big as the Milky Way? The edge of our galaxy is about 1 million light years away, so we cannot send a camera outside the Milky Way to look back at it. Instead, it is easier to look at our neighbours. "Andromeda and Triangulum are both spiral galaxies like the Milky Way," explains Amanda, "so they can give us an idea of how our own galaxy formed and changed over time."

REVEALING THE HIDDEN MESSAGES IN STARLIGHT

Have you ever used a prism to split white light into a rainbow of colours? Astrophysicists do something similar with starlight – they pass it through a narrow slit into a spectrograph which

separates the light according to its wavelength. The amount of light from long (red) to short (blue) wavelengths describes the spectrum of the star and studying this spectrum (a technique known as spectroscopy) can reveal incredible details.

The speed at which a star is moving can be determined by the squashing or stretching of its light to shorter or longer wavelengths. The dominant wavelength is a guide to the star's temperature, as hotter stars tend to glow at shorter wavelengths. And, dips in the spectrum can reveal the star's chemical composition.

Raja and Amanda have been measuring spectra of stars in Andromeda and Triangulum since 2016, using the Keck-II telescope in Hawai'i. This telescope sits at the summit of Maunakea, a dormant volcano and a sacred site to the Indigenous community, so Amanda considers herself "incredibly fortunate" to use the facility for a few nights each year. Before a night at Keck-II, Raja and Amanda use images from the Hubble Space Telescope to identify the stars they want to track so they can point the Keck-II telescope perfectly. The team has now measured spectra of thousands of stars in Triangulum to create the Triangulum Extended (TREX) survey.

THE MYSTERIES OF TRIANGULUM

"Our TREX survey has raised more questions about Triangulum than it has answered!" says Raja. Among the new mysteries is a group of stars in the middle of the galaxy that appear to be 'misbehaving'. While most stars in Triangulum follow a beautiful, orderly pattern like a flock of birds, this unruly bunch are flying around in random directions like a swarm of bees.

The strangest thing is that some of the disorderly stars are relatively young, so they have not yet had time to be disturbed. What has set these 'young and restless' stars into frenzied motion is unclear. Raja and Amanda are continuing to analyse spectra of the stars to see if their chemical makeup can shed light on the galaxy's history.

Another odd thing about Triangulum is that its stars are arranged in an 'S' shape, unlike most galaxies of its size which tend to be arranged as a disc, like a dinner plate. Amanda and Raja are not sure exactly why this is, but suspect Triangulum may have been involved in a galactic collision.

WHAT HAPPENS WHEN GALAXIES COLLIDE?

When two galaxies get close to each other, the stars in one galaxy will be pulled by the gravity of the other. This causes the galaxies to spiral around each other, in a 'dance' lasting billions of years. Eventually they merge into a single galaxy, with a new shape and structure caused by the complex forces of gravity.

Amazingly, nothing actually crashes into anything else when galaxies collide, because the vast majority of a galaxy is empty space. "It's like having two cathedral-sized bubbles, each with a fly in them," explains Amanda. "If you throw these bubbles at each other, the chances of the two flies hitting each other is almost zero."

SHOULD WE BE WORRIED ABOUT A COLLISION WITH ANDROMEDA?

Raja was part of the team that created the first ever digital photo mosaic of the Andromeda galaxy, constructed by stitching together 57 images taken by a ground-based telescope. Subsequent spectroscopy based on wider area images led to the surprising discovery that Andromeda is five times bigger than previously thought. The team determined this by analysing spectra of bright points in wide area images to deduce if each point was an Andromeda star, a Milky Way star in the foreground, or a distant galaxy in the background.

Since then, astronomers have generated much more detailed pictures of Andromeda by combining high-resolution images taken by the Hubble Space Telescope. These new images held an even bigger surprise – Andromeda is heading straight for us. Previously, we knew it was getting closer, but had no idea it was on a collision course. The team Raja belongs to showed this must be the case by comparing two images, taken seven years apart, of stars in Andromeda against the background of distant galaxies. Raja likens this to "watching an insect creep slowly across your wall, using patterned wallpaper as a reference."

PROFESSOR RAJA GUHATHAKURTA

Professor of Astronomy and Astrophysics

DR AMANDA QUIRK

Former PhD Researcher

University of California Santa Cruz, USA

FIELD OF RESEARCH

Galaxy Evolution

RESEARCH PROJECT

Investigating the movement of stars in the Andromeda and Triangulum galaxies

FUNDERS

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The results showed very little movement left or right, up or down. The only conclusion is that Andromeda is moving in a direct line towards the Milky Way. However, the collision is not due for another 4.5 billion years. By then, our Sun will have increased in brightness and made it too hot for liquid water on Earth, so it is unlikely anybody will be alive to see it happen.

HOW DID RAJA BECOME AN ASTROPHYSICIST?

My main interest when I was growing up was art. I loved painting, and still do. My mother was a wonderful artist, as was my older sister and grandmother, so I was surrounded by strong artistic influences. I was also interested in sports and enjoyed both watching and playing lots of different sports.

I liked all kinds of science when I was at school – biology, chemistry, physics. Watching *Life on Earth*, an ecology documentary series narrated by David Attenborough, encouraged me to become a scientist, and trips to the planetarium inspired my love for the stars and motivated me to study astronomy.

After completing my bachelor's degree in India, I came to the US for my PhD. Switching between two very different educational systems was a huge challenge as I was ill-prepared for the style of learning in graduate school. I was used to solving maths, physics, and chemistry problems, but they were invariably problems that someone had set and, therefore, knew the answer to. The open-ended nature of problem solving for a PhD was completely new to me, and this is one of the things that inspired me to establish the Science Internship Program.

The highlight of my career actually has nothing to do with astronomy! Recently, I was offered my first solo art show. Nothing has made me prouder and happier than this opportunity to display my artwork for the public to see.

I think there are parallels between art and astronomy. Both involve observing fine details (I paint and draw portraits of people and animals), creativity, and problem solving. As an astronomer, I envisage how I want to conduct an experiment, but commonly run into issues that must be overcome. As an artist, I envisage how I want to draw a portrait, but sometimes the shading won't work, or the piece won't look as I imagined.

I love the fact that astronomy allows us to look back in time. I think it is fascinating that the light we see in our telescopes on Earth left Andromeda millions of years ago.

RAJA'S TOP TIPS

1. Be patient with yourself. You never know when you will find your passion, but that time will come.

2. Follow things you are interested in, and don't do things just because other people are doing them.

3. If you work hard at something and you really believe in it, good things will happen.

HOW DID AMANDA BECOME AN ASTROPHYSICIST?

I painted a lot as a kid and I swam whenever I could. I had a lot of chronic pain growing up, and swimming was one of the biggest reliefs I had. I was always trying to escape Earth's gravity, because it caused my joints to hurt. These days, I like to go to the beach and draw, and I love snorkelling, though the ocean around Santa Cruz is too cold for me!

I think seeing Saturn in a telescope for the first time was what got me hooked on astronomy. I was at a science centre and my first thought was "How can this be real?" It looked too much like the images I had seen in my textbooks. It was a really inspiring moment for me.

Growing up, I couldn't name a disabled scientist, even though there are many. That always made me feel isolated, so I want to lessen that isolation for others. I created the Graduate Disability Community Group at UCSC, where disabled graduate students can come together. This was a community I had really been missing; now, it's great to feel fully understood by peers. I have also been advocating for STEM programmes to develop more flexibility and to be more accessible.

I want STEM to be a truly inclusive space – anyone who wants to pursue STEM should be able to. Disabled people often have to come up with creative solutions in their lives, and this creativity is really valuable in science. If more disabled scientists are supported in the field, it will lead to more fascinating discoveries.

I work with the Project for Inmate Education programme at UCSC, where I teach algebra and astronomy in Santa Cruz jail facilities. I have developed valuable teaching skills through this opportunity as I have to be a dynamic teacher to ensure I keep everyone engaged, while providing enough background information for students with less familiarity with the concepts. The students enjoy the classes because they allow them to exercise part of their critical thinking that otherwise isn't used in their day-to-day routines.

AMANDA'S TOP TIPS

1. Find a solid support network. In every field there are kind people who will help you be yourself and succeed.

2. Keep hobbies outside of work. It's important to remember that you are worth more than the work you do and to take meaningful breaks.

3. The journey through high school and college is the hardest part, in my opinion. Give yourself credit for the work you're doing at all stages!

THE SCIENCE INTERNSHIP PROGRAM

Raja is the founder of the Science Internship Program (SIP), which gives high school students the chance to work on authentic cutting-edge research at the University of California Santa Cruz. While receiving training from academics to develop their research skills, students complete a project over the summer, allowing them to contribute to scientific discoveries.

HOW DID SIP START?

In 2009, Raja was asked by a local teacher if he would host a few students in his lab, so they could do some astronomy research. He saw that this could benefit everyone – the students would learn what it is like to conduct research, while he would get help analysing his data. That year, three students analysed spectra of stars in Andromeda. One studied the chemical elements in the stars, another calculated how fast the stars were moving, and the third determined which stars were part of the Andromeda galaxy and which were in the Milky Way.

WHY IS IT OKAY TO FAIL?

Unlike in school, where you will be asked to answer questions that have been set by your teacher or textbook, scientists are trying to solve puzzles that nobody has solved before. This means that no one knows the answer, and scientists often get stuck or make mistakes as they search for a solution.

At school, you might feel like you have failed if you do not find the answer, but this is a crucial part of research. "It is important for students to learn that failing is part of the journey to discovery," explains Raja. Behind every big discovery are a thousand 'failed' experiments, so the essential thing is to keep on experimenting.

Students participating in SIP learn the importance of this process of trial and error. "Students are tasked with solving problems that no one has done before, so they need to use their critical thinking skills to find solutions," says Raja. "These solutions may or may not work, but both outcomes are equally useful."

HOW HAS SIP GROWN?

Since Raja invited three students into his lab, SIP has grown every year. By 2022, there were 95 academics hosting 326 students, covering 20 different subjects. The programme has worked hard to become more inclusive by reaching out to students of colour, those from low-income families, and first-generation college aspirants, all of whom face additional barriers to going to university. When the COVID-19 pandemic forced SIP to move online, this opened the programme to students around the world, and Raja hopes that in future SIP will consist of a mix of online and in-person research projects.

WHAT CAN CULTURES REVEAL ABOUT STARS?

NATIVE SKYWATCHERS

Humans have been looking up at the stars long before the Hubble Space Telescope began taking high-resolution images of Andromeda. For tens of thousands of years, communities and civilisations have observed the night sky and tried to understand what is up there. This means the scientific method is only one way of describing the Universe – many cultures have traditional knowledge and beliefs that often hold a deep connection between humans and the stars.

While much of this ancient understanding has been lost due to colonisation and as city lights pollute the night skies, Professor Annette S. Lee, director of Native Skywatchers, is working hard to ensure we do not forget this knowledge.

The aim of Native Skywatchers is to revitalise Indigenous star and Earth knowledge with community-based leadership and from the narrative of the Indigenous voice. In addition, Native Skywatchers encourages people to appreciate both Indigenous knowledge systems of the stars and astronomy, and to forge connections between Indigenous groups and scientists.

WHAT IS TWO-EYED SEEING?

The idea that these two ways of looking at the world, from an Indigenous viewpoint and from a 'scientific' viewpoint, are equally important is known as 'Two-Eyed Seeing', or *Etuaptmumk* in the language of the Mi'kmaq Indigenous peoples.

According to Mi'kmaq elder, Albert Marshall, "Two-Eyed Seeing is learning to see from one eye with the strengths of Indigenous knowledges and ways of knowing, and from the other eye with the strengths of Western knowledges and ways of knowing… but most importantly, learning to use both these eyes together, for the benefit of all."

As the US becomes more diverse, Annette feels Two-Eyed Seeing is more important than ever. "Only when we equally value all the voices of people from diverse perspectives can we begin to tackle some of the crises we are facing today," she says.

WHAT DOES NATIVE SKYWATCHERS DO?

Building on insider relationships, Native Skywatchers records and shares Indigenous knowledge of the stars through a multidisciplinary approach at the intersection of science, art and culture, based on the frameworks of experiential learning, digital storytelling and culturally responsive pedagogy. "By leveraging both the power of science and the power of digital media, enormous change is possible," says Annette. In its workshops, Native Skywatchers has brought together young and old Indigenous knowledge keepers, language and cultural experts, scientists, artists, teachers and communities to share their understandings of astronomy and Indigenous science, and, more importantly, to build community.

WHAT CAN WE SEE IN THE STARS?

Annette and the Native Skywatchers team have researched and designed star maps, to provide a first-glance introduction to Two-Eyed Seeing (**www.annettelee.com/index.php/portfolio/star-maps**). The maps themselves are from the Western science system and are only the beginning 'baby steps' to understanding the larger and deeper philosophical cosmology and practice that is deeply rooted in Indigenous knowledge systems.

"For example, there are many important D(L)akota teachings that relate to To/Tuŋ Wiŋ (Blue/Birth Woman)," explains Annette. "She resides at an important doorway in the stars, right at the centre of the scoop of what non-Indigenous US folks call the Big Dipper. This constellation is part of important D(L)akota teachings of origin, of how we come from the stars. To/Tuŋ Wiŋ is a doorway between the spirit world and the material world, helping those who are coming into (being born) or leaving (dying) this human journey." This same group of seven bright stars is also known as the Wičakiyuhapi Wašihdapi or 'Stretchers and the Mourners'.

Indigenous constellations are brightly coloured on the Native Skywatchers star maps and the Greek constellations are indicated more subtly, located in the background for reference. These maps begin to show a deeply different and layered Indigenous way of looking at the sky through an Ojibwe, D(L)akota, and Ininew-Cree cosmology.

HOW DID ANNETTE BECOME AN ASTRONOMER AND ARTIST?

PROFESSOR ANNETTE S. LEE
Director of Native Skywatchers

Arizona State University, USA
University of Southern Queensland, Australia
University of California Santa Cruz, USA

Annette has always felt a strong connection to the stars. As a member of the Lakota and Ojibwe communities, she believes that humans are made up of four things: body, mind, heart and spirit, and that the spirit is pure star energy. For as long as she can remember she has dreamt about the stars, and those dreams have led her to become both an artist and an astronomer.

Being a scientist and an artist can be difficult at university, where the two disciplines are seen as separate. Her culture, however, told her that science is rooted in the mind and body, while art is rooted in the heart and spirit. Choosing one or the other would be to neglect half of her full self. To pursue both passions, Annette did two undergraduate degrees (in mathematics and art), two master's degrees (in fine arts and astrophysics) and a PhD in astrophysics.

Annette's connection to Indigenous culture has given her a broader perspective than many astronomers, who only learn about the scientific approach. "Indigenous peoples have nurtured relationships with the stars through keen observations, place-based ceremony, navigation and celestial architecture for tens of thousands of years," she says. "The Indigenous relationship with, and knowledge of, the sky is exceptional in that it encompasses mind, body, heart and spirit."

As an astronomy professor and professional artist, Annette is committed to making astronomy more culturally diverse. In 2007, she launched Native Skywatchers as a small initiative to collect traditional knowledge in the Lakota and Ojibwe communities. Since then, it has grown into a wider effort to revitalise Indigenous star knowledge and Annette has worked with communities around the world, including in Hawai'i, Alaska, Aboriginal Australia and Māori New Zealand.

Annette's work has been an inspiration to many. For example, the national parks in the US attract visitors looking for dark, starry skies, making them an ideal location to share traditional astronomy. The National Park Service has therefore begun working with Indigenous communities to provide cultural stargazing experiences.

NATIVE SKYWATCHERS - WE ARE STARDUST

Raja and Annette have teamed up in a collaboration called 'Native Skywatchers - We Are Stardust', to give students the opportunity to explore the scientific and cultural significance of stars. Students video-call astronomers as they make telescope observations, effectively 'eavesdropping' on a night of research at the observatory, and interview cultural experts in their own communities to learn traditional knowledge of the stars.

In 2021, Ruvarashe (Rue) Moyo and Nokutenda (Noku) Saurombe, students at Queen Elizabeth High School in Zimbabwe, took part in We Are Stardust. "I learnt that Two-Eyed Seeing is better than one," says Rue. "We Are Stardust brought together western science and Indigenous knowledge in a beautiful way," adds Noku.

"I learnt that stars are the raw materials of life," says Rue. "Everything on Earth is made of elements that were produced when stars died billions of years ago." Noku describes how "every ingredient in the human body came from elements forged by stars. The oxygen in our lungs, the carbon in our muscles, the calcium in our teeth and the iron in our blood were all created in the interiors of exploded stars."

Rue and Noku also had the opportunity to discover the significance of stars in Zimbabwean culture. "Stars are described as hope, destiny, and freedom," explains Noku, who learnt how different stars symbolise good luck, ambitions, new beginnings, and advancements in life. Rue learnt that most Zimbabwean dances and designs are inspired by the stars and their movement. "I use a small basket every day and never knew that the design on it was inspired by the Milky Way," she says.

Rue hopes to help more young Zimbabweans become curious about space and to become open-minded problem solvers. Her first priority, though, is sustainable development. "I live in a community where some people go to bed hungry and some die of curable diseases. I want to ensure basic resources are accessible to all." Noku's ambition is to become an aerospace engineer, solving the technical challenges needed to put rockets and satellites into space.

NOKUTENDA SAUROMBE AND RUVARASHE MOYO