

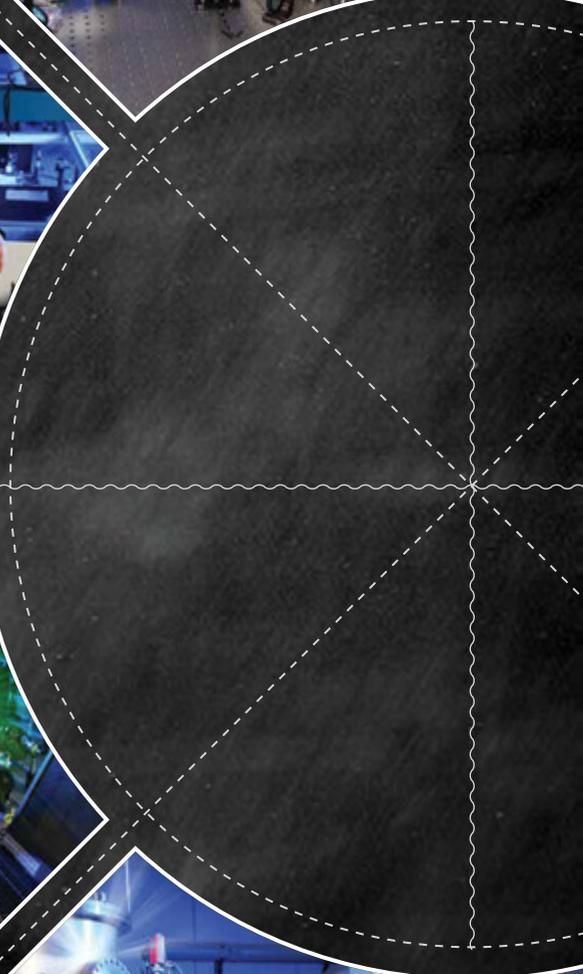


## CAREERS AND OPPORTUNITIES IN PHYSICS



**SAASTA**

South African Agency for Science  
and Technology Advancement



# CAREERS AND OPPORTUNITIES IN PHYSICS

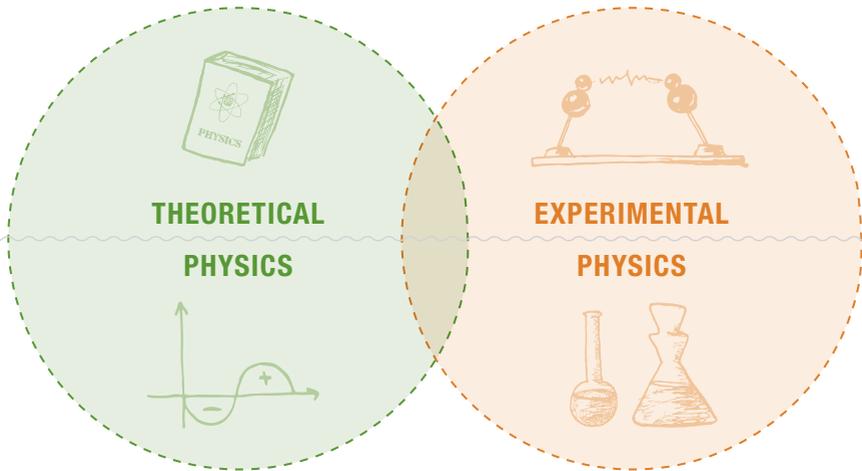
*It's far more than just rocket science*

## What is physics?

In a nutshell, physicists try to figure out how nature works. They address the big questions: What is the universe made of? Why do stars shine? Why is water fluid? Why is the sky blue? Is it true that we are all made of stardust? Why does the universe expand (or ripple) and how will it end?

And, although addressing the big questions, some physicists may well be studying the smallest building blocks of matter. Physicists may design and perform experiments with lasers, particle accelerators, telescopes, mass spectrometers and other equipment. Based on observations, predictions and analysis, they attempt to discover the laws that describe the forces of nature, such as gravity, electromagnetism, and nuclear interactions. They also find ways to apply physical laws and theories to address problems in nuclear energy, electronics, optics, materials, communications, aerospace technology, biology and many more.

It is an awesome fact of human life that scientists can actually answer some of these big questions. Not only that, but the answers are becoming progressively better and better. That is, they are increasingly in agreement with observation.



## THEORETICAL VERSUS EXPERIMENTAL PHYSICS

Some physicists explore and identify basic principles governing the structure and behaviour of matter, the generation and transfer of energy, and the interaction of matter and energy. Others work in practical areas such as the development of advanced materials, electronic and optical devices, and medical equipment. Theoretical physicists do a lot of thinking and calculations on paper and on computer. Experimentalists on the other hand would spend time doing measurements in a laboratory.

Theoretical and experimental physics are two sides of the same coin. These two areas guide each other and there is a constant interplay between the two. Theoretical physicists are concerned with mathematically describing and predicting the physical behaviour of nature. Experimental physicists are concerned with gathering information and testing hypotheses through detailed conceptualisation and realisation of laboratory experiments. Although experimental and theoretical physics are concerned with different aspects of nature, they share the common goal of understanding it. Theory provides the possible explanations of natural phenomena and experiments confirm which of these ideas are applicable.

A prime example of the interplay between theoretical and experimental physics is the work done on the Higgs boson. Theorised in 1964, its existence was only confirmed almost 50 years later. In March 2013, particle physicists working at one of the world's most expensive and complex experimental facilities to date, the Large Hadron Collider (LHC) at CERN (the European Organisation for Nuclear Research), were able to create Higgs bosons and other particles for observation and study. The confirmation of the existence of this particle made headlines around the world as it explains how the building blocks of the universe have mass. Without the influence of a mysterious field spread across the universe, now known as the Higgs field, particles would simply whizz around space at the speed of light rather than clumping together and forming the building blocks of atoms.

The Higgs boson is just one of many examples of how theoretical and experimental physics feed into and guide each other.



## HOW DO I BECOME A PHYSICIST AND WHAT SUBJECTS SHOULD I TAKE?

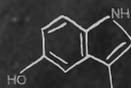
If you are curious, have an enquiring mind and enjoy solving puzzles, especially mathematical puzzles, then you are a potential candidate for a career in physics. Rocks, plants, animals and humans are made of the same particles and these were born 13 700 million years ago at the Big Bang. Are you are intrigued by the fact that we are all stardust? Then physics might be for you.

If you are interested in pursuing a career in physics, you will need to include Mathematics (Maths Literacy is insufficient), Physics and Chemistry on your list of matric subjects. So be sure to work extra hard to achieve good results in these subjects.

*Mathematics*

$$\left(\frac{f(x)}{g(x)}\right)' = \frac{f'(x) \cdot g(x) - f(x) \cdot g'(x)}{g^2(x)}$$

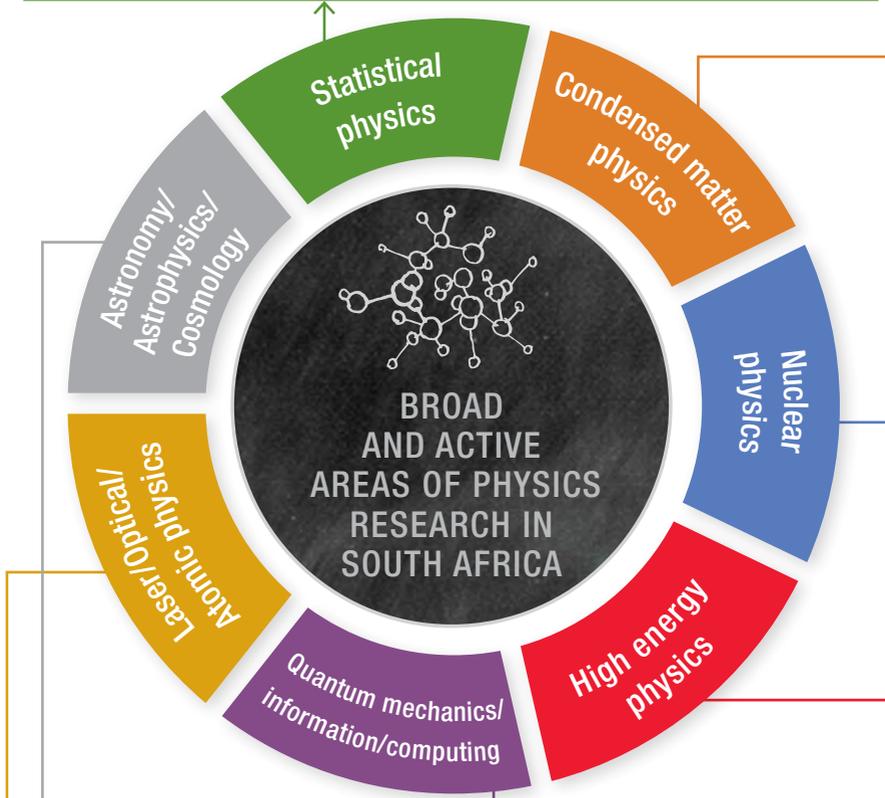
*Physics*



*Chemistry*

Once you have a degree in physics you may pursue a career in engineering, mining, IT or even in the biomedical and financial sectors: practically any industry that requires good analytical and logical thinking skills. Alternatively, you could pursue a postgraduate degree by working under the supervision of more senior scientists. These studies can lead to a career in industry, the possibility of launching of one's own company or a full-time research career at a university or research agency.

Uses methods of probability theory and statistics in solving physical problems involving systems with many particles or constituents. Its applications include many problems in the fields of physics, biology, chemistry, neurology, and even some social sciences, such as sociology. The field of statistical physics is in a phase of rapid change.



Cosmology is the study of the origin, evolution and eventual fate of the universe. Astronomy is one of the oldest sciences. It is the study of celestial objects such as stars, galaxies, planets, moons and nebulae and the physics and chemistry of these objects. Astrophysics refers to the branch of astronomy dealing with the behaviour, physical properties and dynamic processes of celestial objects and phenomena.

Deals with light and its interaction with matter and finds many applications in industry, medicine, engineering, technology and basic research such as quantum information. Several physics departments in the country and the National Laser Centre does work related to this important area of research.

Deals with physical phenomena at nanoscopic scales. Quantum mechanics provides a mathematical description of much of the behaviour and interactions of energy and matter. It has played a significant role in the development of many modern technologies. Quantum information and computation are active fields of endeavour. Quantum computing makes direct use of quantum-mechanical phenomena, such as superposition and entanglement, to perform operations on data. Quantum information is physical information that is held in the state of a quantum system.

The fundamental science of solids and liquids. Almost every aspect of our daily life benefits from research in condensed matter physics. For example, composite materials are used in jet turbines and modern tennis rackets; superconducting magnets are used for medical diagnostics; various solid state sensors and detectors for space exploration and lasers for entertainment, broadband communication, and medical procedures.

Concerns itself with the interactions between nuclear particles such as protons and neutrons and how it determines the properties of and the interactions between the nuclei of atoms. It is important in energy production, e.g., nuclear energy, many medical applications using radio-isotopes and even in space science where the bombardment of satellites by cosmic radiation degrades the materials. iThemba Labs in South Africa and NECSA do work in these and related areas.

High energy physics explores questions about the elementary constituents of matter and energy, the interactions between them, and the nature of space and time. The work done at the Large Hadron Collider and CERN in general is focused on particle physics and high energy physics.

All these areas of research have strong overlaps and involve both experimental and theoretical research.

about these objects with unprecedented detail. These are areas of immense opportunity for bright young minds.

## SKA and SALT

Due to South Africa's ideal geographical location it has a strong tradition in astronomy. In turn, astronomy relies strongly on some of the above areas of research as well as many others. Studies in cosmology, and theoretical particle and nuclear physics can link strongly with the observations to be made in future with the Square Kilometre Array (SKA) and currently with the South African Large Telescope (SALT). To make the most of the data collected by these telescopes, South Africa not only needs more astronomers, but also physicists to provide a theoretical physics underpinning to SKA and SALT observations. Hence more studies of compact stellar objects like white dwarfs, pulsars, and black holes are needed not only to explain observations but also to understand the densest states of matter. When the SKA comes online in the next ten years, we will be able to collect data

## Quantum information and computing

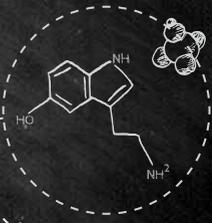
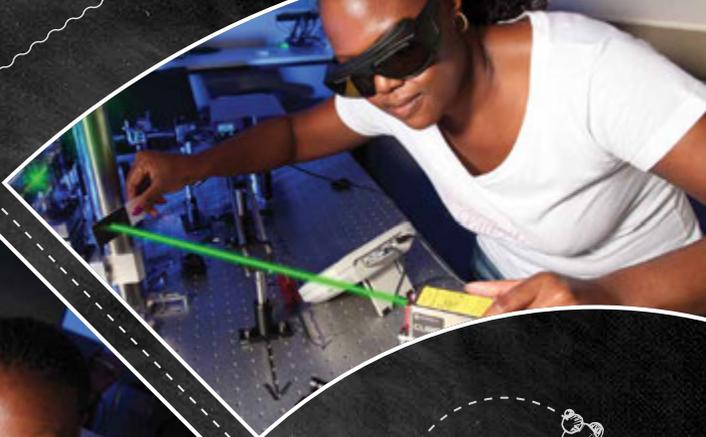
There is also lot of promise and technological future in quantum information and computing, if we can sufficiently control quantum systems. There are some strong groups at various South African research institutions at the moment that are active in quantum computing and quantum information.

As South Africa will never be able to afford facilities such as the LHC at CERN, indeed no single country can as these are multi-national endeavours, it is important that South African physicists are connected with these, and similar future facilities around the world, to ensure that our research and training in physics is at the cutting edge. There are several programmes, such as the SA/CERN collaboration, that offer these contact mechanisms for South African physicists and students.

## South Africa's move towards a knowledge-based economy

South Africa is moving away from a resource-based economy, towards a knowledge-based economy. The country can only achieve this with the help of analytical thinkers, people who can do numerical analysis and people skilled in the mathematical sciences. We must seize the opportunities now to establish capabilities that will provide long-term, sustainable solutions in national priority areas such as health and energy, while boosting economic growth. Physicists will play a crucial role in this transformation. Get on board and enjoy the ride.

## PHYSICISTS' PROFILES



**PATIENCE MTHUNZI**  
OMB – Biophotonist

### Moving ahead faster than a photon of light

Patience is a senior scientist at the National Laser Centre (NLC), at the Council for Scientific and Industrial Research (CSIR). As South Africa's first biophotonics PhD graduate, she is gaining international recognition for her work in this new field, which involves understanding the interaction of photons with biological materials at single cell or even single molecule level. Patience received the country's highest honour, the Order of Mapungubwe, from President Jacob Zuma in 2012 and was named one of Forbes magazine's *20 Young Power Women in Africa*.

### What Patience does

Born in Orlando West, Soweto, she is currently the principal investigator responsible for the Biophotonics Research group within the NLC. Biophotonics is a multidisciplinary science combining among other things biology and photonics, with photonics being the science and technology of generation, manipulation, and detection of photons or quantum units of light.

"This aspect of medical research focuses on the use of laser light for micro-manipulating biological materials to carefully study their intricate processes," explains Patience. "Since this is a relatively new field, I was unable to study biophotonics in South Africa. The course is not offered at local universities. I became the first South African PhD student at the School of Physics and Astronomy, University of St Andrews, Scotland.

*“I focus on optical cell sorting where diseased cell populations are selectively separated from healthy ones using laser tweezers. I also employ lasers for targeted gene delivery into stem cells, leading to their non-invasive evolution for tissue regeneration.”*

In case you were wondering what the OMB at the end of her title stands for, Patience is the youngest recipient of the Order of Mapungubwe, Bronze for her contribution in biochemistry and biophotonics. “When informed of the award, I thought the call from the Presidency was a crank call,” says Patience. “It was only later on that I realised that I would be receiving one of the country’s highest orders. It was a huge privilege and honour.”

### **Biophotonics as a career**

Biophotonics can be described as the development and application of optical techniques, particularly imaging, to the study of biological molecules, cells and tissue. One of the main benefits of using optical techniques is that they preserve the integrity of the biological cells being examined.

The specimens that are imaged with microscopic techniques can be manipulated by the optical tweezers that Patience uses and by laser micro-scalpels – further applications in biophotonics. Their precise wavelength selection and wide coverage; focussability and best spectral resolution; strong power densities and broad spectrum of excitation periods make lasers the most universal light tool for a wide spectrum of applications.

The NLC enables South African industry to improve its global competitiveness and expand market share. The centre works closely with local higher education institutions and supports laser related research at these institutions.

### **Advice to prospective physicists**

“From high school level, ensure that you take science subjects like Mathematics, Physics, Chemistry and Biology,” warns Patience. “After matriculating from Reasōma Secondary School in 1994, I enrolled for a degree in Psychology. However, my deep love for science deflected my attention to a BSc degree, followed by honours and masters and finally my PhD. This was all dependent upon having taken and excelled in those subjects at school.

“If you think physics is for you, you can look forward to a career in which you can discover new things on a daily basis. The more I dig, the more informed I get. I love being mentally stimulated and challenged. My job does precisely that.”



**TJAART KRÜGER**  
Biophysicist

## Studying the inner workings of biological systems with unprecedented precision

Tjaart is a senior lecturer and biophysics research group leader at the University of Pretoria. Physics is ‘in his genes’, with several family members involved in this field of science. In particular, it was his grandfather’s willingness and ability to explain physics concepts in a clear and concise manner that inspired him to follow in his *Oupa’s* footsteps.

### What Tjaart does

Biophysics is an interdisciplinary science using methods of and theories from physics to study biological systems. Biophysics spans all levels of biological organisation, from the molecular scale to whole organisms and entire ecosystems.

Tjaart works on experimental molecular biophysics, applied to natural light-harvesting systems or natural ‘solar cells’. “This is adventurous, pioneering work. Our research has strong application in the development of next-generation bio-inspired solar cells, the investigation of crop failure under drought stress or conditions of high solar irradiation and in the biomedical field.”

Tjaart’s day typically starts with emails and quick tasks before switching to research work, interspersed with meetings with masters and PhD students to determine progress and teach new concepts. “I will also spend time reading research articles, developing new research ideas, working in the lab to help with an experiment, and preparing for seminars or lectures. A substantial amount of time normally goes into writing reports, research articles and grant applications for funding.

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*“There is never a dull moment and research frequently delivers completely new and sometimes unexpected results. The multi-faceted nature of my research involves time to design and build new experimental setups, conduct experiments, analyse and interpret data, write computer scripts to analyse data in new ways and to perform modelling.”*

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Tjaart enjoys sharing his science through research articles, popular articles, conferences and informal discussions.

### Biophysics as a career

Society is facing physical and biological problems of global proportions. How will we continue to get sufficient energy? How can we feed the world's population? How do we remediate global warming? How do we preserve biological diversity? How do we secure clean and plentiful water? These crises require scientific insight and innovation. Biophysics provides the insight and technologies for meeting these challenges.

Biophysics discovers how to modify microorganisms for biofuel and bioelectricity, harnesses microorganisms to clean our water and produce lifesaving drugs. Biophysics pushes back barriers that once seemed insurmountable.

Despite this, there is little activity in this field in South Africa. “Our lab is currently the only group in the country where research in biophysics is conducted from a strong experimental physics point of view,” says Tjaart.

### Advice to prospective biophysicists

“Don't let biology scare you off due to the huge volumes of information you have to learn at school. Biology is an amazing subject and physicists should start to appreciate this. The times are over where physics and biology are considered in isolation,” adds Tjaart. He says biology can only be appreciated at a fundamental level, when viewed through the lens of physics.

“Expand your general knowledge, kindle your interest in physics by reading popular books and articles on physics and make contact with real physicists.” He says role models are very important. If you cannot talk to a real physicist, read biographies of great physicists. This helps you to lay out a career path that is realistic and practical.

“Finally, don't get discouraged by the mathematics, because you will have to wait until you learn calculus to understand most physics. After all, Newton invented calculus in order to solve a physics problem: the orbits of the moon and planets in the solar system!”



**ZAMA KATAMZI**  
Ionospheric Physicist

## The sky's no longer the limit

Zama is a researcher in ionospheric physics at the South African National Space Agency (SANSA) Space Science in Hermanus. As a space scientist, she searches for answers to questions such as: How does the Sun affect satellites and navigation systems in space? What effects does the ionosphere have on radio waves?

## What Zama does

SANSA Space Science hosts Africa's only Space Weather Centre, providing early warnings and forecasts on space weather activity. As such, the institution plays an important role in protecting satellite technology, as well as communication and navigation systems.

Forming part of the worldwide network of magnetic observatories, Zama and her colleagues are responsible for research, infrastructure and data for monitoring the near-earth space environment.

SANSA is one of 13 regional warning centres that form part of the International Space Environment Service's worldwide network monitoring the earth's magnetic field.

Zama says her work is primarily an office job, because she conducts research at her desk. "However, our work differs from month to month. From January to April we are usually busy with teaching and outreach projects. Then our days are filled with preparing and delivering lectures." She says in June and July they attend international conferences and visit partner institutions. "A normal working day will vary between eight to ten hours, depending on the activities."

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Getting published is Zama's favourite reward.

*"It can be discouraging when you work hard on something and it's not producing any results or when your article or research is rejected. On the other hand, this is all forgotten when you finally see your academic article published in a peer reviewed journal."*

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### Space physics as a career

There are several ways to get involved in space physics. Research over a broad range of topics in space physics ranges from the Sun and solar-terrestrial relationships to the interstellar medium that involves both scientific analysis and the development of instruments and satellites.

Many universities active in space research offer courses in space science as part of the advanced physics or geophysics education, and space physics can be chosen as a topic for one's thesis.

The scope of activities at SANSa Space Science, for example, includes fundamental and applied space physics research, postgraduate student training, science advancement, space weather monitoring, and the provision of geomagnetic field-related services on a commercial and private basis.

Theoretical research in space physics is undertaken at certain universities and may focus on heliospheric structure and particle acceleration and propagation, or on cosmology, interplanetary space, and the upper atmosphere (thermosphere and ionosphere).

### Advice to prospective ionospheric physicists

"Set goals for yourself and have timelines to achieve them," advises Zama. "Hard work is rewarding and gets rewarded. Start working hard at school level. Choose your subjects carefully.

"Look out for exhibitions, outreach projects and visits to science research facilities. At SANSa we have a science advancement outreach facility where we encourage young people to explore space science," she says.

According to her this is a very young career field in South Africa and there are vast opportunities. "Our space agency is only four years old; there is still a lot in store for future young scientists. We need more people who want to follow this career."



**HAPPY SITHOLE**

High Performance Computing Director

### Driven to out-compute in order to out-compete

Happy is the director of the Centre for High Performance Computing (CHPC), which is designed to enable South Africa to become globally competitive and to accelerate Africa's socio-economic upliftment through the effective application of high-end cyberinfrastructure. Happy holds a PhD in Physics based on simulation of mineral processing using quantum and atomistic simulation techniques.

### What Happy does

It takes a brave person to accept the challenge of leading an organisation that is responsible for meeting the country's high-end computing needs. The aim of the CHPC is to provide a world-class centre that enables cutting-edge research with high impact on the South African economy.

But Happy is up to the challenge. "My job involves developing strategies for using HPC in different domains of science and engineering. It requires an understanding of the HPC needs of many fields." Fortunately Happy has broad experience having worked as a researcher in materials modelling, a research scientist in the mining sector and a process engineer in the nuclear industry.

Cyberinfrastructure describes research environments that support advanced data, computing and information processing services over the Internet. It's a technological and sociological solution that connects laboratories, data, computers, and people; enabling derivation of novel scientific theories and knowledge.

*“My job does involve getting out of my comfort zone. I constantly interact with many people from different backgrounds. I need to understand technology development and how it impacts on use by scientists and engineers. I need to understand how to sell these problems and opportunities to politicians for funding.”*

Happy has to verify that the centre's HPC systems are operating optimally. He checks in with managers to see if there are any problems. He is also hands-on, sometimes logging in and checking valuable statistics, such as the utilisation of the systems and also responses to users.

The work is not all about the systems. People skills play an important role in Happy's workday. "My diary features meetings with staff, CHPC managers, CSIR management, Department of Science and Technology officials, user groups and suppliers. Besides the meetings, regular discussions with technical staff are essential to properly plan for infrastructure and for the development of strategies for future HPC systems."

Somehow Happy still finds time to work on science projects and supervise students based at different universities.

### High performance computing as a career

Upon finishing a PhD, many dedicated scientists are faced with the tough decision of where to take their careers next. Do they walk the academic road or do they leave the world of academic science for a more stable position elsewhere? Working in HPC is a good alternative and a middle road. It still allows one to play an important part in the latest cutting edge scientific research, while maintaining the stability of a steady job and a good career path.

"The world of HPC is driven by the need to out-compute in order to out-compete," says Happy. "This translates into access to massive computing resources and good skills in using these to solve much bigger problems. This is the exciting crossroads where science and engineering meet computing technology."

Since computing architecture evolves every 18 months, one cannot be caught napping. For a physicist it means consistently looking at applications and how they are affected by technology developments.

### Advice to prospective physicists

"The future of physics in South Africa is good within astronomy, material science and the energy sector," says Happy. "These sectors require well trained physicists. Students should be aware of these opportunities and understand their requirements so that they are well prepared to contribute."



**ANGELA DUDLEY**  
Laser Scientist

### 'Twisted' laser beams for secure data transfer

Angela is a postdoctoral fellow at the CSIR's National Laser Centre (NLC). Her research interest is the use of 'twisted' laser beams for quantum cryptography.

### What Angela does

Angela and colleagues in the Mathematical Optics group at the NLC study various aspects of modern optics, including laser beam shaping, laser beam propagation and novel resonators. They are interested in the mathematical basis of these fields, as well as applications of this research in diverse areas.

Angela's interest is in 'twisted' laser beams that could ultimately result in ground-breaking implications for quantum cryptography studies. The beam doesn't actually map out a twisted-path when moving through space, but it's an invisible property of the beam that has a helical or twisted nature.

"Most of my time is spent on research," says Angela. "I spend a lot of time in the lab building and designing optical systems and writing programs to automate our experiments. Once I've set up an experiment, a lot of time is spent recording and analysing data. Another aspect within research that takes up a decent portion of my time is writing papers.

## Laser science as a career

Laser science or laser physics is concerned with the construction and application of lasers, their design, and the physics involved in their future development.

The huge growth in telecommunications over the last decade can be attributed to new technologies made available through fibre optics and lasers, and the conveying of information by light. Lasers and photonics have underpinned the revolutionary development in information technology and computing.

Angela says one of the reasons she decided to pursue a career in physics – apart from enjoying and having an aptitude for Mathematics and Physics at school – is that there are very few female scientists in South Africa. “My view at university was that if there are only a few people pursuing careers in physics, this would mean less competition and more opportunities. Obviously you need to have passion and skill if you want to capitalise on these opportunities.”

Angela was inspired to pursue a career in physics by her dynamic mentors, as well as her parents who gave her the freedom to follow her own ambitions.

She says South Africa needs more scientists. Although small, the country’s physics research and teaching community is resilient and talented. Despite problems such as poor training of Physics students in schools and under-funding of research initiatives, the country hosts some globally competitive research institutes. “The future of physics in South Africa lies within the physics community,” says Angela. “We need to be innovative and engage bright, young people so that our physics developments of today become the technology of tomorrow.”

*“Some of the less frequent tasks that can influence my day are: structuring papers in preparation for a conference; reviewing grant applications; lecturing (for about three weeks of the year at a local university) and mentoring vacation students.”*

## Advice to prospective physicists

“If you enjoy and have some skill in Mathematics and Physics, you already possess one of the most important characteristics of a physicist,” says Angela. Some other personal attributes include: curiosity, inventiveness and enjoying problem-solving. Being meticulous and methodical are also necessary qualities, especially if you plan on being an experimental physicist.

Successful physicists need to communicate their research, verbally and in writing. However, Angela says, “I feel that (with some perseverance) these skills can be developed during your studies and early career.”

Patience and perseverance may be required. “It took me 10 years to obtain a PhD after finishing high school. Always capitalise on opportunities. You don’t know where it may lead or what doors it may open.”



**CAROLINE ZUNCKEL**  
Astrophysicist

## Testing theories of the origin and nature of the universe

Caroline is a Physics lecturer at the University of KwaZulu-Natal with research interests in astrophysics. Astrophysics deals with the physics of the universe and the objects therein, including the planets, stars, galaxies and interstellar material. As a cosmologist, she studies the origin, evolution and eventual fate of the universe.

### What Caroline does

Caroline focuses on testing cosmological theories using observational data and evaluating whether extensions to the standard concordance model (the standard model of Big Bang cosmology) are warranted.

She is interested in determining what datasets – such as galaxy surveys and supernovae – can tell us about the nature and fundamental building blocks of the universe (such as dark energy and dark matter), as well as about its beginnings.

“The most exciting aspect of my career is the potential to make important discoveries. In astrophysics, there is much that we do not yet understand about the universe. This means that we have the opportunity to contribute to the field in a substantial way.”

Findings are made all the time, so Caroline kicks off her working day by checking an online repository of the latest journal articles on astrophysics.

During the semester, she spends part of her day compiling material for the course that she is teaching, preparing for and delivering lectures. Her day can also include attending a seminar on astrophysics – or another field of physics, a meeting with postgraduate students or colleagues to discuss research projects, or administrative meetings.

*“My favourite part of the day is working on my research. This usually involves writing a piece of code to carry out a complex calculation, analysing results from a computation, writing a journal article or just sitting and thinking about how to proceed.”*

### Astrophysics as a career

Caroline emphasises that research in astrophysics is important to society because it pushes the frontiers of our understanding of our own existence. “My research focuses on dark energy, the driving force behind the current, accelerated expansion of the universe. It might not have direct implications for life on earth, but understanding what dark energy is will give us essential clues about the nature of the universe and how it (and we) came to be.”

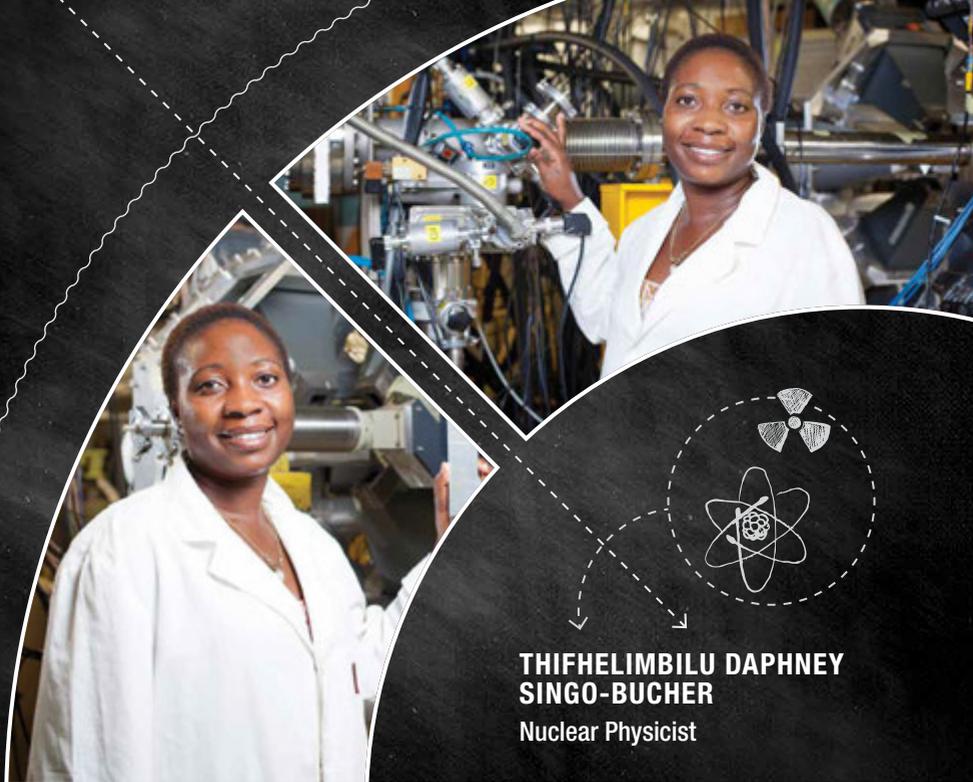
Like numerous astrophysicists around the world, it was Carl Sagan’s TV series *Cosmos* – based on the book by the same name – that first fascinated Caroline as a 12-year-old. This fascination grew and in her undergraduate years, Caroline found physics to be the most challenging and the subject which tackles the questions that she finds most interesting.

Astrophysics has been identified as one of South Africa’s geographic advantage fields and for this reason research in this area has a high priority status in our country. In addition to a myriad other astrophysics experiments, South Africa will host the lion’s share of the Square Kilometer Array. This provides young people interested in physics with the opportunity to be at the forefront of one of the largest and most exciting scientific endeavours.

The government also recognises the skills that an education in science affords and has channelled huge resources into skills development in maths and physics.

### Advice to prospective physicists

“Follow the path that interests you and you will be successful.” But, Caroline warns, astrophysics is not always moonlight and roses. “Because our work is novel, we can encounter obstacles. We may find after months of work that results are neither interesting nor tractable, in which case we have seemingly wasted our time.” Research sails through uncharted intellectual territory, so outcomes are not always known. However, this is why such fascinating things emerge – the most interesting results are the ones that you least expect.



**THIFHELIBILU DAPHNEY  
SINGO-BUCHER**  
Nuclear Physicist

### Investigating the behaviour of atomic nuclei

Daphney is an experimental nuclear physicist at South Africa's high-tech iThemba LABS nuclear science facility. She has worked hard to overcome many challenges, having started out her journey as the impoverished daughter of a domestic worker in rural Limpopo. Like any dedicated parent, Daphney's mom did everything to get her talented daughter an education, including selling home-brewed beer to raise funds for studies.

### What Daphney does

Not many people on the planet spend their working day bombarding target nuclei with protons in a sub-atomic particle accelerator. Working at South Africa's iThemba LABS, Daphney and her research group perform fundamental research, where they study the properties of unstable short-lived nuclei in order to expand their knowledge of nuclear structure.

*"These nuclei are produced in the lab by bombarding the target nuclei with the projectile nuclei or particles such as protons, to form excited compound nuclei," explains Daphney. "Compound nuclei de-excite by emitting particles such as protons and neutrons, to produce a nuclei of interest, which are unstable and decay further to ground state by emitting gamma-rays."*

These gamma-rays are measured by instruments sensitive to gamma radiation known as high purity germanium detectors.

From these studies the team is able to validate new theories, confirm the results of previous work performed by local or international physicists, and solve new and existing problems.

Daphney's workdays are varied. She may spend time performing measurements at the experimental vault, or writing a programing code that can be used to read and sort the data from iThemba LABS' new segmented gamma-ray detector. She could spend some time reading research articles to expand her knowledge and familiarise herself with current trends in research.

Daphney spends some of her time supervising and motivating postgraduate students. She also spends time interacting with high school learners as part of the iThemba LABS outreach programme.

### **Nuclear physics as a career**

Nuclear physics studies the constituents and interactions of atomic nuclei. It is most commonly associated with nuclear power generation and nuclear weapons technology. However, the research has provided application in many fields including: nuclear medicine, magnetic resonance imaging, ion implantation in materials engineering and radiocarbon dating in geology and archaeology.

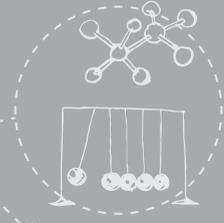
Particle physics evolved out of nuclear physics and the two are typically taught in close association.

Daphney believes physics is an exciting intellectual adventure that inspires young and old, and expands the frontiers of our knowledge about nature. "With physics we can improve quality of life by providing the basic understanding necessary for developing new instrumentation and techniques. Physics contributes to technological infrastructure and provides trained personnel to take advantage of scientific advances and discoveries."

### **Advice to prospective physicists**

As a young woman from a small village in South Africa, Daphney never thought she could make a career for herself in physics. But she did. "As my mother always said, 'Education is the husband that will never let you down'." This quote went viral on Twitter, after Daphney addressed the 2010 TED Conference in California in the US – standing tall and proud in her dazzling, traditional Venda outfit.

She brought 2 000 of the world's elite thinkers to their feet when speaking of her journey from impoverished daughter of a domestic worker to PhD researcher in nuclear physics. Through her speech, Google donated 1 million U.S dollars to the African Institute of Mathematical Sciences where she completed her postgraduate diploma.



**ABDUL MIRZA**  
Quantum Physicist

## Quantum communication research launches spin-off company

Abdul is a postdoctoral fellow at the University of KwaZulu-Natal (UKZN). He manages experimental research in quantum communication at the Centre for Quantum Technology and is CEO of QZN Technology, a spin-off company of the university that focusses on commercialising his research group's output. Abdul was recognised as one of the Top 200 Young South Africans by the *Mail and Guardian* in 2013.

### What Abdul does

Being in the right place at the right moment is important. Abdul was one of the central figures behind the success of the 2010 FIFA World Cup communications system when his PhD studies and the need for state-of-the-art encrypted communication security coincided.

A natural entrepreneurial spirit kicked in a few years ago when Abdul's research led to the establishment of a company, with the support of UKZN, which focuses on the commercialisation of research. Currently its commercial activities focus on quantum and classical encryption.

Abdul's quantum communication projects have included the QuantumCity project and the 2010 FIFA Soccer World Cup Quantum Stadium project. These projects involved quantum technology that ensured encrypted communication security around the World Cup and the Moses Mabhida Stadium.

Besides the academic side of his work and managing experimental research, Abdul has attended various entrepreneurship courses to assist in the process of managing a start-up company.

He loves what he does and says the challenge of defining the new direction of future technology is what keeps him excited.

*“Many physicists work on futuristic technology or theories that may one day become standard technology for the person in the street. Identifying and solving each challenge as a small step towards this eventual goal is a ‘natural high’ that is most definitely addictive.”*

### Quantum physics as a career

Quantum physics or mechanics (also known as quantum theory) is a branch of physics which deals with physical phenomena at nanoscopic scales. It departs from classical mechanics primarily at the quantum realm of atomic and subatomic scales. Quantum mechanics provides a mathematical description of much of the dual particle-like and wave-like behaviour and interactions of energy and matter.

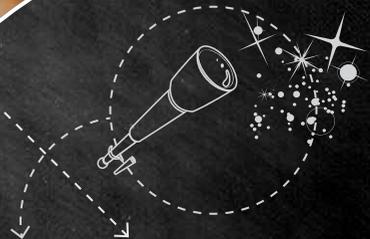
“I like to call physicists fundamental engineers,” says Abdul. “The job of a physicist is to discover and improve upon current theories and technologies that may be used in the improvement of peoples’ lives in the future.” The quantum physicist considers theoretical aspects of science and finds ways to apply it to ease the needs of society. Once the physicists have identified and provided fundamental proof for the system, engineers can build on this platform to further develop and optimise a final prototype and solution.

Physicists are the standard bearers of technological advancement. A perfect example is that of electromagnetic waves and electronics that eventually matured into mobile phones. While a career in pure physics provides benefits, many physicists branch out into the financial world as analysts. They are sought after due to their problem-solving skills.

“Time management is critical in a multifaceted job such as mine,” warns Abdul. “Intricate planning ensures that you provide enough time for the business, research and students.”

### Advice to prospective physicists

“A career in physics is definitely a long road to walk, with many sacrifices along the way. The personal and financial benefits of a career in pure physics are often recovered later than many other careers. But if entrepreneurship is in your blood, it is definitely worth the wait.” And adds Abdul, “If you have a passion for discovery and want to challenge yourself to something new every day, then physics is most definitely a choice to consider.”



**KAVILAN MOODLEY**  
Astrophysics and Cosmology

## Probing the early universe and grappling with dark energy

Kavi is an associate professor in mathematics, statistics and computer science at the University of KwaZulu-Natal (UKZN). His primary research interests are in astrophysics, astronomy and cosmology.

### What Kavi does

Kavi's work focuses on confronting theories of the universe with data from large astronomical telescopes. In particular, his research investigates how measurements of the leftover heat from the Big Bang, in combination with large surveys of galaxies, may be used to probe the universe.

He loves his job and says that, "Being able to engage in research at the frontiers of science provides the opportunity to discover exciting new results. Scientific progress moves so rapidly and the discoveries we are making are truly fascinating."

Astronomers have discovered hundreds of new planets outside of our solar system. Their ultimate goal is to find other planets that could host life. "We are uncovering the secrets of black holes, and grappling with the nature of the mysterious dark energy that fills our universe," says Kavi. "Being able to work with bright young scientific minds on these problems adds to the excitement of research."

He says that since taking up an academic position, his work now entails also managing research groups, spending time with students and administrative responsibilities, in addition to research.

*“My greatest challenge is dealing with things that are not research or teaching. Administration is the one thing that most academics hate! On the flip side is the positive challenge of tackling new research projects and building a thriving research group.”*

### **Astrophysics as a career**

The awarding of the major component of the R26-billion Square Kilometre Array (SKA) mega radio telescope to South Africa will open doors to a wealth of new knowledge and the promise of exciting job and study opportunities. Scientists are optimistic that the SKA will allow many new discoveries about how the universe was formed and its composition.

Kavi is very optimistic about the future of physics in South Africa. He says government has invested in a number of initiatives, including a national theoretical physics institute and numerous national facilities that support physics research around the country in a wide range of areas. “In astrophysics we can expect significant growth on the back of the cutting-edge advances that the SKA will bring. There will be many opportunities for future young scientists to do something novel and world-leading in this field.”

The Astrophysics and Cosmology Research Unit at UKZN, at which Kavi is based, has partnered closely with the South African SKA Project (Saskap) since its inception nearly a decade ago, and now hosts a node of the project’s astronomy undergraduate bursary programme that will train the next generation of South African astronomers.

“This is a very good time to get involved in this dynamic field of physics,” says Kavi. “The SKA will create a technological revolution and improve our understanding of, and fascination for, the universe. Deep questions regarding our origins will be addressed. There’s never been a better time to pursue a career in science and engineering and in physics in particular.”

### **Advice to prospective physicists**

“Build your knowledge foundation on the basis of independent learning and enquiry. Be confident and ask lots of questions,” advises Kavi.

“Get involved in research projects at undergraduate level. Be ambitious – it is worthwhile to take calculated risks. Embrace the positive aspects of a research career – travel, building collaborations, working in a global context. Success will come from a broad understanding of your subject and a deep technical understanding of your area of specialisation.” Kavi’s web page: <http://www.acru.ukzn.ac.za/kavilan-moodley/>



**ADRIANA MARAIS**  
Quantum Biologist

## Exploring the first millionth of a second of photosynthesis

Adriana is a PhD student at the University of KwaZulu-Natal (UKZN). She explores quantum effects in photosynthesis. Adriana was recently shortlisted in the application process for the *Mars One* colony project to become a pioneer and take a one-way trip to the red planet.

### What Adriana does

At the time of writing, Adriana was putting the final touches to her thesis and hoping to submit within weeks. She is a PhD student in the Quantum Research Group at UKZN.

Her thesis deals with aspects of photosynthesis where quantum mechanics plays a role. “We are investigating the very early stages of photosynthesis – up to the first one millionth of a second!” explains Adriana. “That is where sunlight is converted into the charge-separated states necessary for Adenosine triphosphate (ATP) production and the rest of photosynthesis to take place.”

She says surprisingly, these very early processes are nearly 100% efficient – almost no photons or electrons are lost. “We are trying to understand how nature does it so well.”

Adriana says a typical day at work involves reading journal articles, building mathematical models and consulting her supervisors when unsure of how to proceed. “It is important to know what other researchers around the world think of the same problems that we are trying to solve, so research visits and conferences a few times a year help,” she adds.

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*“At work we also drink a lot of coffee, spend a lot of time on the internet and discussing all sorts of problems that exist in the world. We are problem-solvers after all.”*

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In terms of her shortlisting for the Mars One colony project, scheduled to depart in 2024, Adriana is circumspect but undaunted. “For me it is worth sacrificing life on Earth in order to be part of a mission that establishes people on Mars, and possibly finds evidence of life on another planet.” Funding for the programme will be largely through TV rights for the expedition with cameras following the selected final 24 colonists from training through to the eight-month shuttle trip, and following their life on Mars.

Marais says she has the characteristics demanded of the applicants, including resilience, adaptability, curiosity, an ability to trust, creativity and resourcefulness, as well as a unique research passion, which is the search for evidence of the earliest life forms.

### **Quantum biology as a career**

Increasing numbers of scientists are turning to quantum mechanics to better explain the living world. Life is one of the most bizarre phenomena in the whole universe and is difficult to account for by classical models.

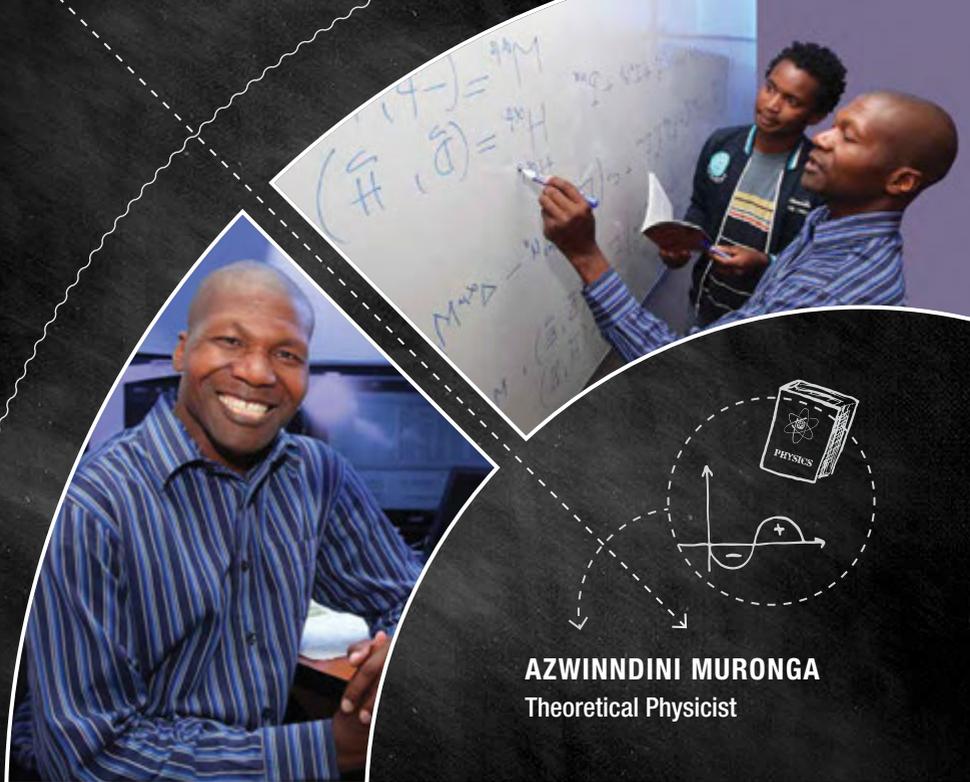
“Research in quantum biology promises to contribute to the development of renewable energy technologies essential for our continued existence on this planet and perhaps others,” says Adriana. “It raises fascinating questions about the origins and nature of life itself.”

She says more recently, they have been investigating the potential relation between magnetic field effects and mechanisms of protection against harmful free-radicals in photosynthesis. This research may have important implications for living organisms in general, with the same free radicals being associated with aging and disease.

The interdisciplinary nature of quantum biology means that physicists, chemists and biologists have to learn to speak each other’s languages, which takes time. But the field is expected to grow in the coming years.

### **Advice to prospective physicists**

If you have ever had questions about why reality is the way it is, physics is the body of knowledge that tries to answer these questions on a fundamental level. “My advice to aspiring physicists is to study hard, read, read, read, never stop asking questions and be joyful that you are participating in the pursuit of knowledge as your life’s work.”



**AZWINDINI MURONGA**  
Theoretical Physicist

### Top researcher finds time to champion science development in SA

Azwinndini is an associate professor at the University of Johannesburg (UJ) and director of the UJ Soweto Science Centre. He teaches and pursues research, while championing science development. His introduction to formal education was modest – classes in the primary school in the rural villages of Lwamondo in Limpopo took place under trees. From these humble beginnings a life-long love of learning was born. Today he is the acknowledged voice of science in rural and disadvantaged areas.

#### What Azwinndini does

As a young herdboyc looking after goats and cattle in the forest, Azwinndini fell in love with nature and started questioning things that were considered taboo.

“Watching my mom make homemade beer made me curious about the processes involved,” he says.

*“The night sky in the villages without street lights made me wonder about the heavens above.”*

## Theoretical physics as a career

“We have seen the rapid evolution of a new and dynamic science and technology system in our country,” says Azwinndini. “Strategic, high-level human capacity development and the coming of age of big science in South Africa ensures that the future of physics is bright.” He says the massive increase in funding, new projects such as the Square Kilometre Array and institutions such as the Centre for High Performance Computing bring growth and a new era of optimism.

The physics profession has received a boost with the establishment of an executive office for the SA Institute of Physics and the establishment of the National Institute for Theoretical Physics.

## Advice to prospective physicists

“You must be committed and passionate about physics to be successful in any physics-related career,” warns Azwinndini.

“There are many benefits to society brought by physics. A career in physics is exciting and the future of physics is bright. For students who want to pursue such a career, now is the time, especially in niche areas such as biophysics, material science, nanotechnology, energy, and many more. Opportunities have never been better. A physics graduate can work in academia, in industry, in finances.”

Inspired by his high school principal who later became his university physics lecturer Azwinndini decided to pursue a career in physics. Today he holds two positions concurrently, namely that of lecturer and researcher at UJ and that of director of the Soweto Science Centre.

He has made outstanding contributions to theoretical physics. His thesis work on causal second order viscous relativistic fluid dynamics was seminal and is now incorporated in large, state-of-the-art computer codes written around the world to model collisions between nuclei at high energy. Azwinndini is considered one of the leading scientists in the relativistic treatment of viscosity.

As a champion for science development in South Africa, he has been involved in setting up the physics undergraduate research programme and in reshaping the graduate physics programme. He runs the internship programme for theoretical physics students from across the country.

As the director of the Soweto Science Centre, Azwinndini has helped build the foundation for and establish scientific programmes that benefit students from previously disadvantaged communities. He also coordinates science awareness and outreach activities and engages personally with students from various communities.

This dedicated physicist still somehow finds time in the day for telephonic interviews on a scientific topic with radio and TV stations, among others the Phalaphala FM radio station.

In 2014 he received the prestigious National Science and Technology Forum - BHP Billiton award for science communication.



**CLAUDIA ZANDER**  
Quantum Physicist

### On the precipice of an information processing revolution?

Claudia is a physics lecturer at the University of Pretoria with a research interest in quantum entanglement, quantum evolution and the emerging field of the physics of information.

### What Claudia does

As a lecturer, Claudia enjoys contributing to students' understanding of how the world around us works, inspiring them to continue studying Physics and enabling them to improve their analytical skills. In her other role as a researcher she says, "Conducting scientific research is wonderful and the thrill of discovery unique. Every day I learn something new and the field of quantum information offers a great variety of challenges."

Claudia's research systematically explores facets of the concepts of quantum information and entanglement.

Quantum entanglement is a special connection between pairs or groups of quantum systems, or any objects described by quantum mechanics. Each particle has its own quantum state. Sometimes, two particles can act on one another and become an entangled system. When a pair or group of particles can only be described with one big quantum state for the lot, and not as a bunch of little quantum states put together, we say the particles are 'entangled'.

Claudia's thesis produced a variety of interesting new results and presented an alternative proof of a certain theorem. The work leading up to her thesis resulted in no less than five publications in peer reviewed science research journals.

"It is a privilege to be part of an international research community, to be able to contribute to the fundamental understanding of quantum information and discover new aspects of quantum entanglement," she adds.

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*"I find it exciting to explore various facets of the concepts of information and entanglement, which are of great importance both from the fundamental and practical points of view. Research on the different aspects of the physics of information may lead to a profound revolution in information processing and communication technology."*

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### Quantum information as a career

Claudia highly recommends physics and the exciting new field of quantum information as a career.

Physics is an international enterprise which plays a pivotal role in the future progress of humankind. Fundamental knowledge needed for future technological advances which are crucial for the continuation of the economic progress of the world, is generated by physics. "Physics is an intellectual adventure that enhances our understanding of other important disciplines, such as geology, agriculture, chemistry, biology, environmental sciences, astrophysics and cosmology."

Scientists are trying to use quantum entanglement for many different purposes. This includes sending completely secret messages and making computers faster than we ever thought possible. However, entanglement between a pair of particles is a very delicate thing and is easily destroyed. Because of this, it is difficult to use quantum entanglement to do these things. Currently, many scientists are working on making more robust systems where entanglement lasts longer, in order to try and do these things more easily.

### Advice to prospective physicists

"For high school students I would recommend reading popular books and journals on physics and to try and make contact with real physicists," says Claudia. She firmly believes that being involved in physics projects is another excellent way to connect with the wonderful and stimulating world of physics.

"Undergraduate Physics students I would advise to speak with the researchers in their department in order to lay out a career path that is realistic and practical and also to get an overview of possible research topics. Since physics provides analytical skills needed for solving problems, it opens the door to many career options."



**ZEBLON VILAKAZI**  
Nuclear Physicist

### Juggling higher education leadership and high spin physics

Despite coming from a disadvantaged background, Zebulon Vilakazi – who was recently appointed University of the Witwatersrand (Wits) Deputy Vice-Chancellor: Research – has made his mark in international physics. He completed a postdoctoral fellowship at one of the world’s largest and most respected centres for scientific research – the Centre for Nuclear Research (CERN) in Geneva, Switzerland.

### What Zebulon does

Zebulon recently joined the executive team at Wits. In this leadership position, he oversees 22 South African Research Chairs, 13 research institutes, 16 research units, four research groups, six Centres of Excellence and some 300 rated scientists.

*“I look forward with great excitement to this opportunity to play a key role in supporting and nurturing research at Wits, my proud alma mater. I am excited to be back in the university environment after spending eight years in science management.”*

In addition to this considerable responsibility, he continues to pursue a research career. His research interests include heavy-ion collisions at ultra-relativistic energies and computational physics – in relation to GRID computing. He has more than 100 refereed articles in nuclear and high energy physics and is a regular invitee for talks and presentations at conferences and seminars.

Zeblon has worked with many international physics bodies and working groups. Prior to his appointment to Wits, he headed up iThemba LABS, an National Research Foundation Facility. In the past Zeblon also served as head of Research and Development at the South African Nuclear Energy Corporation.

### **Nuclear physics as a career**

“Physics is an excellent choice of career for any promising young student of science and mathematics,” says Zeblon. “I use every opportunity, when there is a gathering of budding young scientists, to exhort them to seriously consider a career in the exciting world of physics.”

Though South Africans have been working with CERN since 2002, the country only officially joined as a collaborator thanks to Department of Science and Technology funding in 2007-08. “We are putting together a long-term plan for South African involvement at the Large Hadron Collider (LHC). It is a magnet for students who are attracted by the exciting science being conducted there,” he says. “In recent years, top-class experts and young scientists from abroad have joined South African institutions to be part of this programme.”

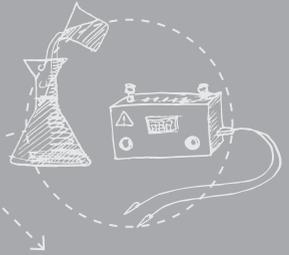
Zeblon was a group leader of the University of Cape Town (UCT) team that contributed to the development of the High-level Trigger (HLT) tracker for the ALICE experiment at the LHC. This effort involved the design of algorithms using a highly complex real time data transportation framework. “This was the first group on the African continent to independently launch an effort of this magnitude at frontier level,” he says proudly. “The trigger was stress tested in Cape Town and delivered successfully for integration and implementation when the collider was commissioned in 2008.”

From the initial success of establishing a High Energy Physics group in Cape Town, a more expanded SA-CERN programme involving five local institutes came about. “Having been able to pioneer these efforts – despite some challenges notwithstanding, to an extent that this programme is now recognised as a key strategic flagship programme – is indeed a rewarding achievement,” says Zeblon.

### **Advice to prospective physicists**

“Our country holds great promise and South Africa needs to continue to engage in fundamental research. In order to achieve our dreams for a better life for all, we need all you young talented minds to work hard, get good grades and pursue careers in science and technology and in physics in particular.”

Hailing from Katlehong on the East Rand, Zeblon knows what it is like to work hard in order to get ahead.



**SONWABILE ARTHUR NGCEZU**  
Medical Physicist and Dosimetrist

### A measure of excellence

Sonwabile is a scientist and research and development (R&D) dosimetrist at the National Metrology Institute of South Africa (NMISA). His work involves the calibration of dosimetric equipment and maintenance of the dosimetric national standard. He is also responsible for research and development.

### What Sonwabile does

Sonwabile is a medical physicist working as a metrologist and dosimetrist. He is busy with his PhD.

Dosimetry is defined as the accurate measurement of doses, especially of radiation. A medical dosimetrist, for example, is part of the radiation oncology team, which helps treat cancer patients via radiation therapy.

Sonwabile worked for some time in the medical field, but his career has now taken him to the hub of metrology in South Africa. NMISA is responsible for maintaining the International System of Units (SI units) and for maintaining and developing primary scientific standards of physical quantities for South Africa.

*“My work involves two main routine activities,” explains Sonwabile. “The first is the calibration of dosimetric equipment and maintaining of the dosimetric national standard. The second one is research and development.”*

South Africa needs a sound and effective national measurement system to be able to compete internationally. NMISA plays a vital role in underpinning South Africa's industrial competitiveness, by providing vital elements of the national technical infrastructure.

On a practical level, this means Sonwabile's typical day would be a mix of performing measurements in the laboratory and then analysis and reporting of results at the office. "A great deal of time is also spent in the office (ultimately the lab) researching, developing new capabilities by communicating with our customers and stakeholders, and the international community," he adds. This also involves the reviewing of the scientific literature, to effectively keep the lab up to date and relevant to South Africa.

### Dosimetry and medical physics as a career

"As a dosimetrist, it's exciting to work in the world of metrology, the science of accurate measurement," says Sonwabile. "I embrace the tremendous responsibility to provide the country with traceability to international standards of measurements.

"As a qualified medical physicist I have found it most exciting to apply my physics background in the medical field."

Medical physics is generally speaking the application of physics concepts, theories and methods to medicine or healthcare. Medical physics departments may be found in hospitals or universities. Areas of specialty are widely varied in scope and breadth. They may range from clinical physiology or physiological measurement, to radiation protection and audiology.

There are many jobs for medical physicists in medical schools, hospitals, and clinics. Many medical physicists make a career as a consultant to hospitals and other users of their services. Such careers begin with a postgraduate degree in physics, medical physics, or radiation biology.

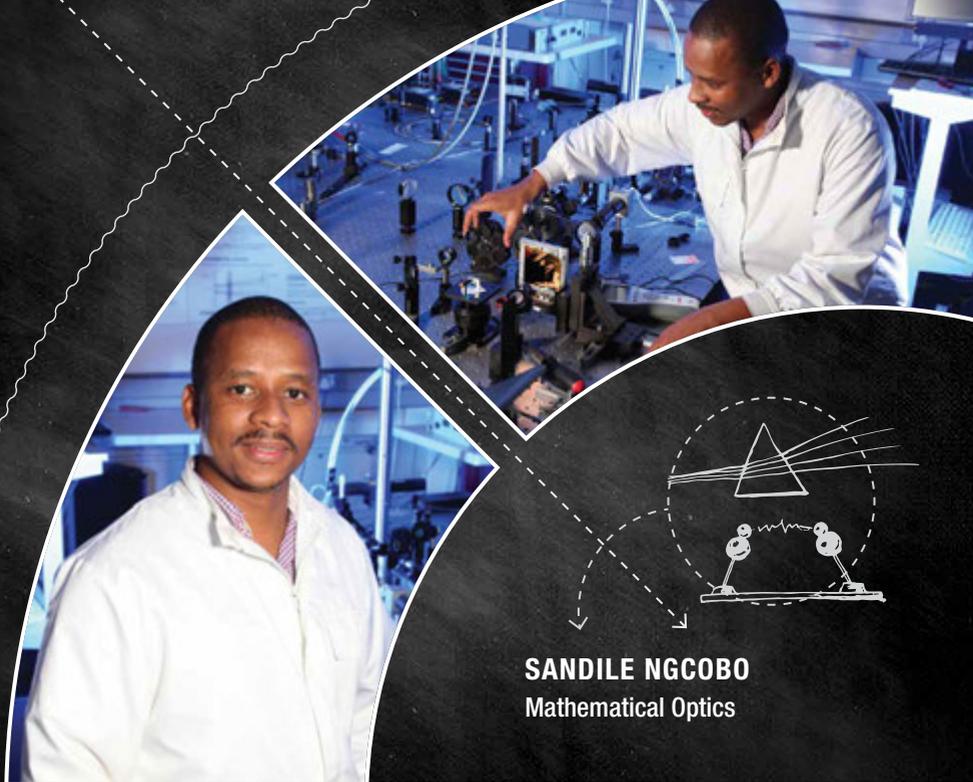
Metrologists and dosimetrists too are in high demand.

Precision measurement, even with the most advanced equipment, is a highly skilled profession, and a good metrologist is worth his or her weight in gold. Globally, the number of people who have the knowledge and skill to perform equipment calibration and precision measurements is dwindling. So if your interest is piqued, this would be a lucrative avenue to pursue.

### Advice to prospective physicists

Sonwabile is a passionate advocate for the physics profession. "With determination and hard work, it is 100% possible to be part of a group of individuals (physicists) who have a tremendous influence/potential in changing the world. Don't believe the myth that 'maths and science are difficult subjects'. Like all worthy undertakings, a sound understanding of maths and science is assured through hard work and determination.

"Physics will open up a world of opportunities for you!!!!"



**SANDILE NGCOBO**  
Mathematical Optics

### Digital laser redefines beam shaping

Sandile is a researcher within the Mathematical Optics research group at the National Laser Centre (NLC), based at the CSIR. His team is responsible for developing the world's first digital laser. This digital laser allows researchers or manufacturers to reshape a laser beam without having to spend money on expensive equipment.

### What Sandile does

Sandile designs novel laser resonators. Resonators consist of an active media and two mirrors on each side, one of which is highly reflective, while the other is only partially reflective and allows emission of laser light. His work also entails laser beam shaping and laser beam propagation.

During 2013, the NLC announced a breakthrough in terms of how to control the size and shape of a laser beam using a computer. The breakthrough forms part of Sandile's doctorate, which is on 'controlling the light inside lasers'. Sandile's research has shown it is possible to alter the beam from inside the laser by replacing one of the mirrors with a computer interface.

Not bad for a young researcher originally from Kwa-Mafunze village in KwaZulu-Natal!

Manufacturers will now be able to digitally control laser beams from within the laser to improve functionality and performance.

In a traditional laser, if one requires a different beam, you either have to replace one of the mirrors or manipulate the beam once it emerges from the laser using a spatial light modulator. Lasers cost thousands of rands, and altering them is a lengthy and costly exercise.

The NLC's potentially lucrative invention has huge implications for health, communications and manufacturing.

*“The most exciting thing about my career is the opportunity it provides. I am able to come up with ideas for new projects and see them through from conception, to being proven and demonstrated in laboratory, and to the delivery of a final product that can be used by ordinary people to improve their lives or businesses.”*

Sandile has been designing lasers for the past four years and was part of the team that designed and developed a two-micron, high-power, slab laser. This laser has the highest output power in the world. The laser can be used in many applications such as laser materials processing and in laser surgery.

### Mathematical optics as a career

Mathematical optics explores the mathematical basis of various aspects of modern optics as well as the applications of this research in diverse fields.

Promising students are always sought after. There is always a demand for high quality mathematics applied to real research problems in optics. This field of endeavour also does extensive experimental work to confirm ideas and predictions. Thus hands-on skills are also highly valued.

Sandile says his typical day at work involves researching the latest laser developments and trying to invent new laser devices by coming up with better ideas on how to solve the new, current and future applications that will require lasers. “I also have to do laboratory research where I implement my understanding of physics and I have to do a lot of calculations, computer programming and engineering to solve challenges.”

### Advice to prospective physicists

“My advice to young students is that sacrifice and a willingness to learn physics, especially at young age, will ensure you succeed in this field of science,” concludes Sandile.

“The future of physics in South Africa looks very good. We have a large population of young people who could potentially be exposed to science at a young age. This will mean in years to come that we could have a large number of physicists who could come up with new inventions and open up new industries, thereby creating a lot of work opportunities and improving people's lives locally and globally.”



**NTOMBIZONKE KHESWA**  
Nuclear Physics (Target Maker)

### **Bullseye: these targets are made of a very thin foil or gas**

Ntombi is South Africa's only female nuclear target maker. She works at iThemba LABS, where she is responsible for manufacturing "target nuclei" for nuclear physics experiments.

### **What Ntombi does**

As a target marker at the iThemba Laboratory for Accelerator Based Sciences (iThemba LABS), Ntombi is responsible for manufacturing "target nuclei" that are used mainly by the nuclear physicists for their research.

Targets are prepared using various methods depending on the chemical and physical properties of materials to be used, as well as the requirements of a particular experiment in terms of thickness, size and the amount of impurities that can be tolerated. These targets can either be in a form of a very thin foil, thicker foil or gas. Various techniques are used to manufacture and characterise target materials. For example, thin films are produced by carefully rolling thicker materials.

Targets are prepared from both naturally occurring materials and stable isotopes, which are supplied either in pure elemental form or as stable compounds.

*“The nuclear physics community requires the production of a large variety of targets made from elements throughout the periodic table,” explains Ntombi. “Target preparation is often crucial to the success of an experiment and it is of the utmost importance that the target conforms to the experimental requirements with regard to purity, composition and very importantly, thickness.”*

In principle, these experiments require an accelerated beam of particles that interacts with the nuclei (target material) such that the researchers can study whatever processes occur within the nuclei. Basically without the target material, there is no experiment.

Ntombi is enthusiastic about her highly specialised career and is actively involved in the international nuclear target-making community. She is a standing board member of the International Nuclear Target Development Society.

### Target making as a career

Target makers are engaged in sample preparations for research in nuclear physics, nuclear energy, biology, geology, space science, medical diagnosis and cancer treatment, and for the calibration of scientific instruments.

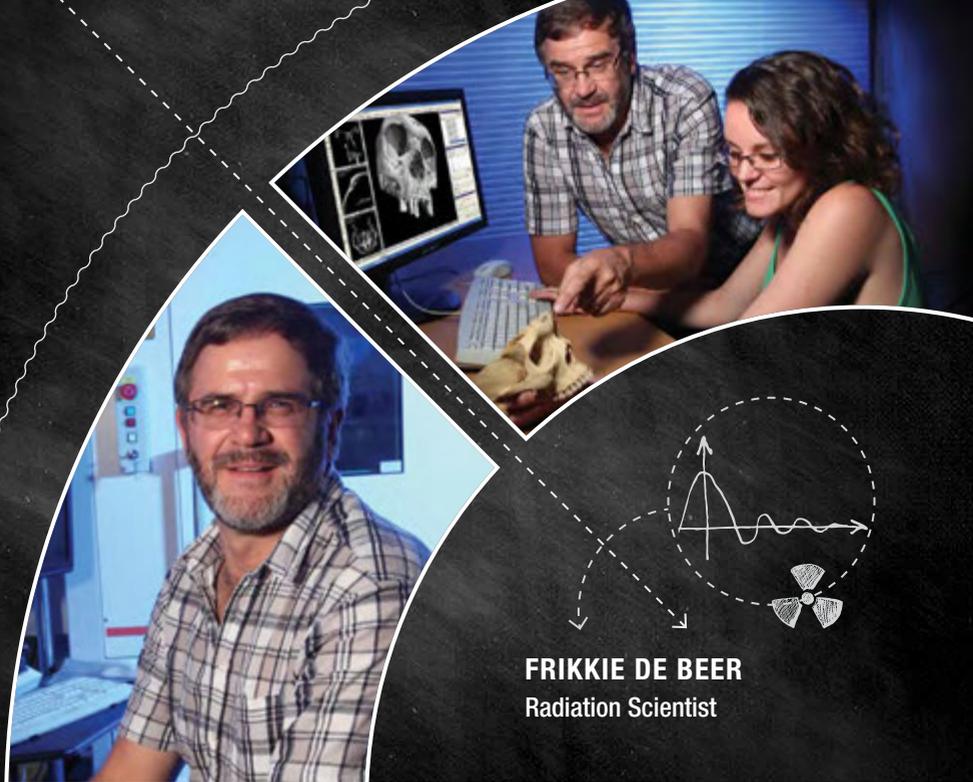
Upon invention of the accelerator, the era of the target maker began. Generally, the increase in sophistication of target making paralleled the increasingly complex developments in accelerator and nuclear physics. It is the target preparer who must provide the defined condition of the target sample – a complicated process involving the disciplines of chemistry, physics, metallurgy, ceramics, and material science.

Target makers have unique technical backgrounds in a wide variety of scientific disciplines.

Since she works in the experimental nuclear physics department at iThemba LABS, Ntombi’s field of interest combines her chemistry background with the experimental side of nuclear physics. iThemba LABS is a research facility of the National Research Foundation and the only one of its kind in our continent. This facility is used by more than 200 scientist and students from local institutions and international partners. This multidisciplinary research facility provides facilities for basic and applied research using particle beams, and particle radiotherapy for the treatment of cancer.

### Advice to prospective physicists

“Considering that South Africa is planning a nuclear build programme and the direction the country is taking with regards to its nuclear energy programme to drive its industrial development, this is a perfect period for next generation nuclear physicist to advance their skills,” says Ntombi. “To be able to succeed in this field besides working very hard, you need to do well in physical science and mathematics. My advice to you all is to follow your dreams... and never feel ashamed to ask if you don’t know.”



**FRIKKIE DE BEER**  
Radiation Scientist

### Harnessing SA's nuclear research reactor for non-destructive testing

Frikkie de Beer is an expert instrument scientist in X-ray and neutron radiography and tomography. He works as the chief scientist in the Radiation Science department at the South African Nuclear Energy Corporation (Necsa).

### What Frikkie does

The analytical techniques of the neutron radiography facility linked to South Africa's SAFARI-1 research reactor at Necsa can be used for free by postgraduate students, as well as researchers from science councils and museums for a multitude of applications.

The facility uses penetrating radiation in a wide range of scientific fields including palaeosciences, geosciences, engineering, biosciences, entomology and anatomy.

Commissioned in 1965, SAFARI-1 is still going strong. It is the country's only nuclear research reactor. This 20-Megawatt, tank-in-pool type nuclear reactor is owned and operated by Necsa. Located at Pelindaba, west of Pretoria, it is used primarily for commercialisation, but also for the provision of support services that provide strong academic and industrial links.

In addition to hosting postgraduate students and researchers from external organisations, Frikkie leads a team of instrument scientists. He and his colleagues, "Guide and assist the external researchers in their research while utilising the equipment".

Frikkie's day kicks off with responding to emails, before meeting clients, who have booked 'beam time' on one of the instruments. With co-instrument scientists, he plans and discusses the scanning experiments to be conducted at either the micro-focus X-ray tomography or neutron tomography facilities. Some guidance is given on analytical evaluation of the results. This evaluation typically is done on high performance computers using specialised analytical software.

Other daily tasks would include meetings with the instrument scientists to discuss their needs, postgraduate studies and work. He may spend time finalising tomography scanning schedules. "During lunch, while eating the sandwiches my wife has prepared for me, I will quickly read and respond to emails I may have received while in the lab."

His afternoon involves activities such as chairing meetings to plan practical experiments to be conducted at SAFARI-1. Frikkie also spends time presenting at Necsa colloquia about overseas visits or discussing results obtained at an international facility he has visited. He also finds time for experiments.

### Radiation science as a career

Neutron radiography (N-ray) and X-radiography (X-ray) and tomography are complementary, non-destructive testing techniques. Frikkie says these techniques are used in many scientific fields, with each day delivering new challenges, opportunities and excitement; especially when applied to new fields of research.

Frikkie enjoys being part of an international community. "But most satisfactory of all is the fact that I can render a service which is unique in South Africa and the world. I enjoy enhancing knowledge on the safe handling of radiation and its utilisation for the benefit of mankind."

A major challenge is to keep up with the amount of information, technology development and research applications. "There is not enough time in a day to do what I want to do, apart from what I have to do."

### Advice to prospective physicists

"Once you start dreaming about becoming a physicist, work as hard as possible, with understanding, towards that dream. Do not stop dreaming... and learn from your mistakes. Somebody remarked once: *If you haven't made a mistake, you have not made anything at all.*"

Frikkie calls on the government to launch a long-term plan to train and produce highly qualified maths and science teachers. "Physics departments at universities should be able to deliver quality students so that South Africa can compete and contribute to global knowledge. We need to make a difference in Africa and the world – a good example is the South African physicist Allan Cormack who won the Nobel Prize in Medicine for developing the CT-scanner."



**CLAIRE LEE**  
Particle Physics

### **Present in CERN at the moment of Higgs boson discovery**

Claire Lee is a PhD candidate in high energy physics at the University of Johannesburg (UJ), working on the ATLAS Experiment at CERN's Large Hadron Collider (LHC) in Geneva, Switzerland.

### **What Claire does**

Claire has loved physics and astronomy since she was young and is interested in particular in the fundamental forces that shape the universe in which we live.

Her work covers a new method of measuring the energy of collisions at the LHC at CERN with the ATLAS detector. This method is used in a number of analyses including the search for the Higgs boson. Claire's timing could not have been better: she was working at ATLAS at the time that the existence of the Higgs boson was confirmed, fifty years after it was first theorised.

The LHC is the world's largest and highest energy particle accelerator. This machine runs for 27 kilometres in tunnels underground and is designed to shoot very small particles (protons) into each other at high speeds. When the particles hit each other, their energy is converted into many different particles, and sensitive detectors keep track of the new pieces that are created.

Since 2010, the LHC has been running at ever-increasing luminosities, producing proton-proton collisions at world record energies in order for physicists working on the data to be able to investigate some of

the great mysteries in physics. “I am lucky enough to be one of those physicists,” says Claire. “I helped with the search for the Higgs boson, the particle hypothesised and now confirmed to give mass to the basic particles in the universe.”

Claire and her family relocated to Geneva so she could complete her PhD right here where the experiment takes place.

“The experiment I’m working on is called ATLAS (there are four major LHC experiments). ATLAS is a general-purpose detector. This collaboration totals at somewhere over 3000 people. Not everybody is at CERN, of course, but it definitely is the best place to be as you are right in the hot seat where the action is happening, the air buzzes with new results and new theories, and you can bump into Nobel Prize winners in the cafeteria at lunch.

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*“The great thing about working at CERN is that you really are in the centre of so much of what is happening. Even my office is in the corridor where the World Wide Web was developed in the 1990s. I am part of a group from Academia Sinica in Taiwan, and I share the office with other students and post docs. It’s great to be in here, if I run into a problem I usually just have to turn around and ask one of the other people in the room.”*

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### Particle physics as a career

Particle physics experiments like ATLAS are constantly unearthing new discoveries that teach us more about the forces that shape the universe. Among the possible unknowns are extra dimensions of space, unification of fundamental forces, and evidence for new particles such as dark matter candidates in the universe. Following the discovery of the Higgs boson, further data will allow in-depth investigation of the boson’s properties and thereby of the origin of mass.

The work of particle physicists will be complete when all the questions to the mysteries of the universe have been answered. Since new questions are popping up all the time, this is an exciting career to pursue, with endless possibilities.

### Advice to prospective physicists

Claire says, “Maths is just a tool. Some people are better at using the tool than others. Ditto for computing, we use massive-scale computer programs to help us analyse the data from the LHC, and the better you are at programming the easier it will be for you to get the results you need. But my point is that with practise, anyone can become good at using a tool.

“So my advice to future particle physicists is this: hone your skills at maths and programming. They will definitely help you along your way, but don’t forget the passion and curiosity that led you here in the first place. Keep questioning, keep investigating, and you will be a great physicist!”

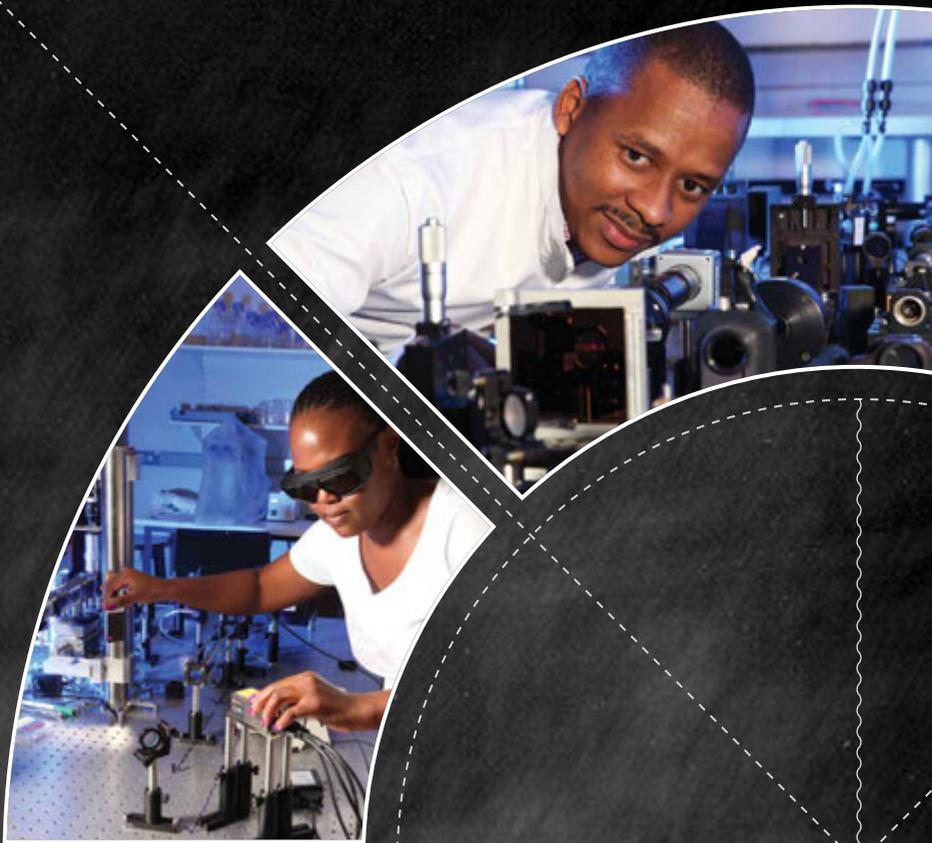
## GLOSSARY

<b>Big Bang</b>	A scientific theory about how the universe started, and then made the groups of stars (called galaxies) we see today. In the Big Bang theory, the universe began as very hot, small, and dense, with no stars, atoms, form, or structure (called a "singularity"). Then about 14 billion years ago, space expanded very quickly, resulting in the formation of atoms, which eventually led to the creation of stars and galaxies. The universe is still expanding today, but getting colder as well.
<b>Biophotonics</b>	A combination of biology and photonics, with photonics being the science and technology of generation, manipulation, and detection of photons, quantum units of light.
<b>Biophysics</b>	An interdisciplinary science using methods of and theories from physics to study biological systems.
<b>CERN</b>	The world's biggest laboratory for particle physics located near Geneva, Switzerland. The name stands for Centre Européen de Recherche Nucleaire (European Centre for Nuclear Research). CERN was founded in 1954. Today 21 nations are members of the organisation.
<b>Cosmology</b>	The study of the origin, evolution, and eventual fate of the universe.
<b>Dark matter</b>	In astronomy, a type of matter speculated to be responsible for huge parts of the universe.
<b>Fermion</b>	One of the things that everything is made of. Fermions are really small and do not weigh much. Fermions can be thought of as the building blocks of matter because atoms are made up of fermions. An electron (a particle of electricity) is a fermion, but a photon (a particle of light) is not. Fermions are special because you cannot put two of them in the same place at the same time, if they have the same quantum numbers.
<b>General relativity</b>	A theory of space and time. Created by Albert Einstein, the central idea of general relativity is that space and time are two aspects of spacetime. Spacetime is curved when there is gravity, matter, energy, and momentum.
<b>Higgs boson / Higgs particle</b>	A particle that gives mass to other particles. The particle was found in March 2013 using the Large Hadron Collider. It is part of the Standard Model in physics, which means it is found everywhere. It is one of the 17 particles in the Standard Model. Bosons are particles responsible for all physical forces except gravity. These particles are believed to exist for less than a septillionth of a second.

<b>Higgs boson jokes</b>	A Higgs boson enters a Catholic church and the priest advised that they unfortunately could not accommodate bosons to which the HB replied "Well then, without me you'll have no Mass"!
<b>Laser science / laser physics</b>	A branch of optics that describes the theory and practice of lasers. Laser is an acronym for Light Amplification by Stimulated Emission of Radiation.
<b>Large Hadron Collider (LHC)</b>	The world's biggest and most powerful particle accelerator. It's a machine used to shoot very small particles into each other at high speeds. When the particles hit each other, their energy is converted into many different particles, and sensitive detectors keep track of the pieces that are created.
<b>Metrology</b>	The science of measurement, embracing both experimental and theoretical determinations at any level of uncertainty in any field of science and technology.
<b>Neutron radiography</b>	Is a very efficient tool to enhance investigations in the field of non-destructive testing (NDT) as well as in many fundamental research applications. Neutron radiography is, however, suitable for a number of tasks impossible for conventional x-ray radiography. The advantage of neutrons compared to x-rays is the ability to image light elements (i.e. with low atomic numbers) such as hydrogen, water, carbon etc. In addition, neutrons penetrate heavy elements (i.e. with high atomic numbers) such as lead, titanium.
<b>Particle accelerator / atom smasher</b>	A machine that makes tiny particles travel at very high speeds. Accelerators work by pushing particles like electrons, protons, or nuclei with electric fields and by steering them with magnetic fields. Their main use is to study particle physics. The largest accelerators are used to study subatomic particles; smaller accelerators are used to study atomic nuclei (the big part at the middle of atoms) and make radioactive materials.
<b>Particle physics</b>	Study of really tiny pieces of things, known as particles. These particles are the really small pieces that build up the world around us.
<b>Quantum biology</b>	Application of quantum mechanics to biological objects and problems. Usually refers to applications of the "non-trivial" quantum features such as superposition, nonlocality, entanglement and tunneling, as opposed to the "trivial" but ubiquitous quantum mechanical nature of chemical bonding, ionization, and other phenomena that are the basis of the fundamental biophysics and biochemistry of organisms.

## GLOSSARY (continued)

<b>Quantum entanglement</b>	A special connection between pairs or groups of quantum systems, or any objects described by quantum mechanics. Quantum entanglement is one of the biggest parts of quantum mechanics that makes it hard to understand in terms of the everyday world.
<b>Quantum mechanics / quantum physics / quantum theory</b>	A branch of physics which deals with physical phenomena at nanoscopic scales. It departs from classical mechanics primarily at the quantum realm of atomic and subatomic length scales. Quantum mechanics provides a mathematical description of much of the dual particle-like and wave-like behaviour and interactions of energy and matter.
<b>Stable isotopes</b>	Chemical isotopes that may or may not be radioactive, but if radioactive, have half-lives too long to be measured.
<b>Standard Model</b>	Combined with General Relativity is currently the most accepted explanation of how the universe works.
<b>Supersymmetry</b>	A theory (commonly found in some forms of string theory) that says that when the universe was made, there was also the same number of theoretical "superparticles" created. If this theory is true, it would at least double the number of particles in the universe. Supersymmetry may create more than one copy, since there are many dimensions (some string theories predict up to 11). Many scientists believe in supersymmetry because it solves many inconsistencies in the Standard Model of physics.
<b>Tomography</b>	Imaging by sections or sectioning, through the use of any kind of penetrating wave. Tomography may involve gathering projection data from multiple directions and feeding the data into a tomographic reconstruction software algorithm processed by a computer.



## Studying physics

Physics is not just rocket science. It is a route to many possibilities. Although their work doesn't always have an obvious application to everyday life, by pushing technology to the limits physicists are responsible for lots of useful spin-offs. These include new ways of sterilising food using particle accelerators, to the invention of the World Wide Web. They may also spend time finding out how frogs can levitate, how much toast you could make with a bolt of lightning or how earthquakes happen.

To follow a career in physics you need to ensure that your subjects include Mathematics, Physics and Chemistry. If you need a bursary, your average mark will have to be in the upper 70% or higher. **You will also need a healthy dose of curiosity!**

**Many South African universities offer postgraduate courses in physics at their science faculties.**

### **Nelson Mandela Metropolitan University**

<http://physics.nmmu.ac.za/>

### **North-West University**

<http://www.nwu.ac.za/physics>

### **Rhodes University**

<https://www.ru.ac.za/physicsandelectronics/>

### **University of Cape Town**

<http://www.phy.uct.ac.za/>

### **University of Fort Hare**

<http://www.ufh.ac.za/faculties/sna/>

### **University of the Free State**

<http://www.ufs.ac.za/content.aspx?uid=26>

### **Medical Physics**

<http://health.ufs.ac.za/content.aspx?DCode=037>

### **University of Johannesburg**

<http://www.uj.ac.za/EN/Faculties/science/departments/physics/Pages/default.aspx>

### **University of KwaZulu-Natal**

<http://scp.ukzn.ac.za/Homepage.aspx>

### **University of Limpopo**

[http://www.ul.ac.za/index.php?Entity=phy\\_geo](http://www.ul.ac.za/index.php?Entity=phy_geo)

### **University of Pretoria**

<http://web.up.ac.za/default.asp?ipkCategoryID=2050>

### **University of South Africa**

<http://www.unisa.ac.za/Default.asp?Cmd=ViewContent&ContentID=223>

### **University of Stellenbosch**

<http://academic.sun.ac.za/physics/>

### **University of Venda**

<http://www.univen.ac.za/index.php?Entity=Physics&Sch=8>

### **University of the Western Cape**

<http://www.uwc.ac.za/Faculties/NS/Physics/Pages/default.aspx>

### **University of the Witwatersrand**

<http://www.wits.ac.za/physics/>

### **University of Zululand**

<http://www.unizulu.ac.za/faculties/faculty-of-science/3about-us/>

### **Walter Sisulu University**

<http://www.wsu.ac.za/academic/academic.php?id=faculties>

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## Other physics bodies in SA

South African Institute of Physics: promotes study and research in physics and related subjects and furthers the exchange of knowledge among physicists by means of publications and conferences. <http://www.saip.org.za/>

National Institute for Theoretical Physics (NITheP): an NRF Centre of Excellence that leads research programmes and educational opportunities in the field of theoretical physics in South Africa and Africa. <http://www.nithep.ac.za/>

**Fun pages:** Marvin & Milo, the official physics.org facebook account from the Institute of Physics

<https://www.facebook.com/pages/Marvin-Milo/30754874738>