'An eye-opening book that shows us all the amazing work India's scientists are doing and teaches us about the most cutting-edge research too. I thoroughly enjoyed it.' Professor ASHUTOSH SHARMA, Former Secretary, Department of Science and Technology, Government of India

INDIA'S SCIENCE GENIUSES

(And the Problems They Are Solving)

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India's Science Geniuses

(And the Problems They Are Solving)

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with
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juggernaut

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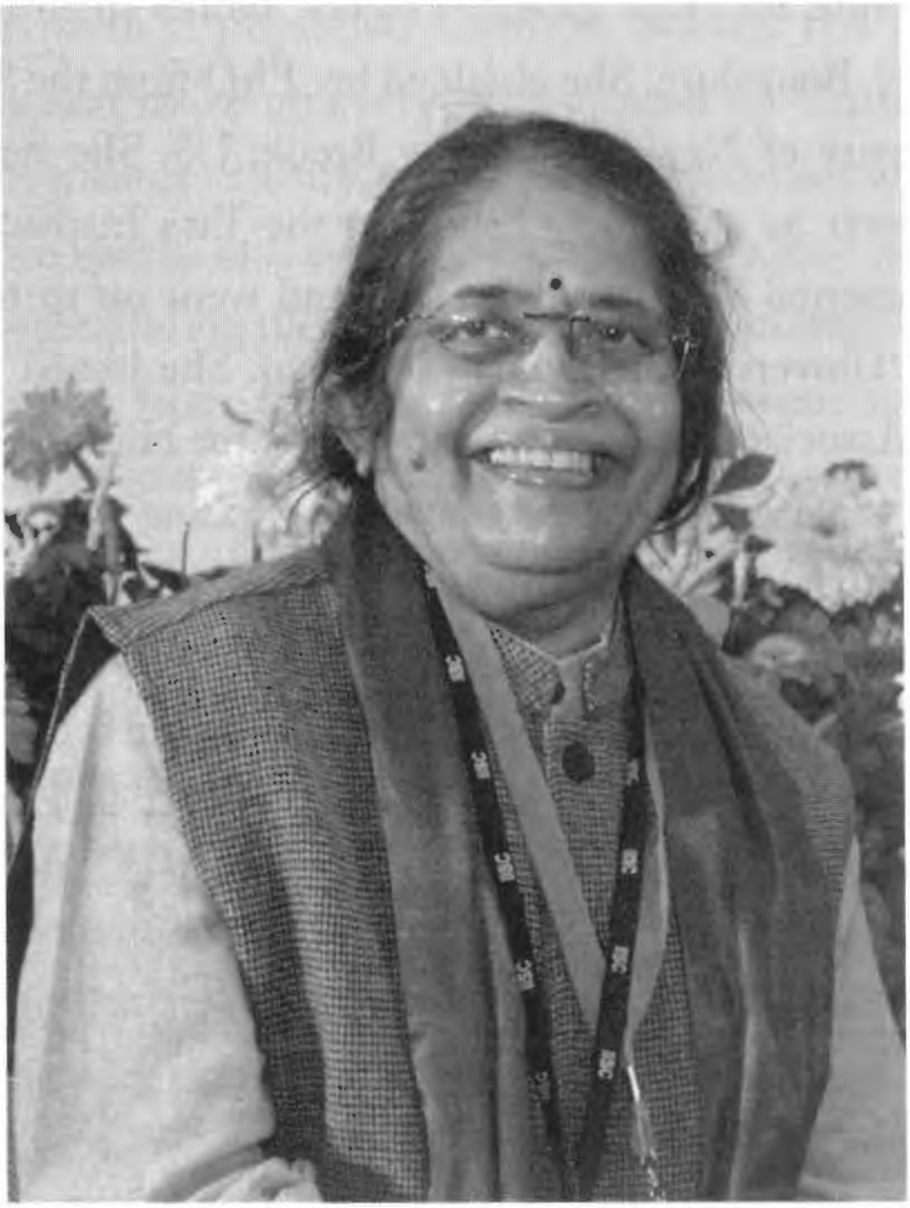
What can tracing the footprints of elementary particles tell us?

Rohini Godbole applies her knowledge of physics to explore the building blocks of matter.



From Rohini Godbole's personal collection

Padma Shri Rohini Godbole is a retired Professor at the Centre for High Energy Physics, Indian Institute of Science, Bengaluru. She obtained her PhD from the State University of New York, Stony Brook, US. She started her career as a Visiting Fellow at the Tata Institute of Fundamental Research, Mumbai, and went on to teach at the University of Bombay, Mumbai. She joined IISc as an Associate Professor at the Centre for High Energy Physics in 1995. Her career involved working with many international collaborations at CERN (Geneva) and DESY (Hamburg), and she has been a visiting faculty at many international universities and institutes. She has worked extensively on different aspects of Particle Physics phenomenology over the past three decades, authoring nearly 300 research publications.

An illustrious scientist who cheers for India's progress in its scientific pursuits. An enthusiastic science communicator who loves inspiring young minds. A flagbearer of women in science. A decorated researcher with many accolades, including the Padma Shri and the French Order of Merit. A physicist who is renowned for her work in the context of the search for the Higgs boson at CERN, the European Organization for Nuclear Research. She is Rohini Godbole, an honorary professor at IISc, Bengaluru. Starting out as the first scientist in her family, Godbole achieved many scientific milestones in her career spanning more than four decades, some of which were firsts for any woman in India.

As a particle physicist, Godbole studies the nature of particles that make up everything around us. Until the turn of the twentieth century, scientists believed that all that we see – from specks of dust to the gigantic galaxies – were made up of atoms, the smallest building blocks of matter. The word 'atom' comes from the Greek word that means indivisible. With the discovery of electrons and the nucleus, the world of Particle Physics took a fascinating turn, and atoms were no longer indivisible! Many path-breaking experiments showed that atoms consisted of smaller 'subatomic' particles. These included negatively charged electrons going around the tiny nucleus, which contained positively charged protons and chargeless neutrons.

In the last few decades, scientists have discovered new elementary particles that have redrawn this image. We now know that 'matter particles', called quarks and leptons, make up everything around us. Quarks are weird in that they cannot exist freely; they quickly combine to form particles called hadrons. Protons and neutrons, which contain a few quarks, are also hadrons. Leptons, on the other hand, exist on their own. Electrons are a type of lepton. With the discovery of many types of quarks and leptons, scientists have put together a new model that could better explain the enigma of nature. Called the Standard Model of Particle Physics, it describes how quarks and leptons interact and how they behave under different conditions and how they make up everything around us in the Universe!

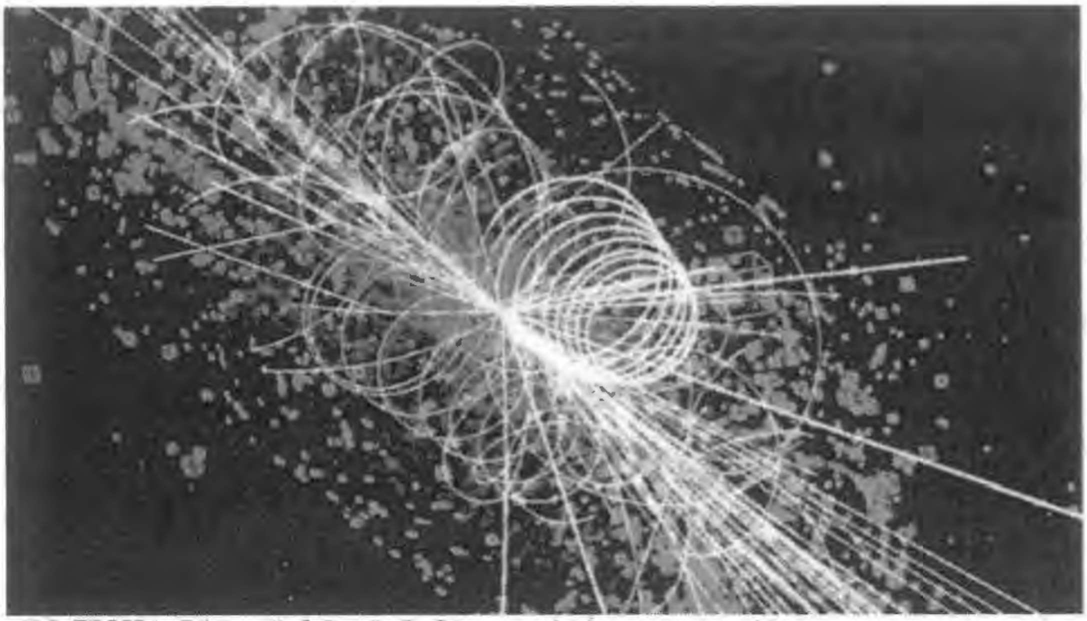
Nature has four fundamental forces – gravitation, electromagnetism, the weak force and the strong force. When a fruit falls from a tree, we see the gravitational force in action. A light bulb going on due to electricity shows electromagnetism at play. The strong and the weak forces are invisible to our naked eye as they act inside atoms. The strong force holds together quarks to form protons/neutrons and many other hadrons. It also holds neutrons and protons inside a nucleus, whereas the weak forces facilitate the nuclear decay processes that happen inside the Sun. Apart from matter particles, the Standard Model also contains interaction/force particles, called bosons, corresponding to each of these four forces. Particles communicate with each other by exchanging these force particles. For example, a photon carries the electromagnetic force; eight different types of gluons carry the strong force, and W and Z bosons carry the weak force. Although not described in the Standard Model, scientists predict that graviton – particles yet to be discovered – is the force particle for gravity.

Experimental physicists use the theoretical knowledge of the behaviour of particles to find them in particle colliders

– giant machines that generate head-on collisions between fast-moving protons. Due to the enormous impact, the protons become so hot that their temperature reaches a million times higher than the Sun's, and they eventually break up into matter and force particles. Various detectors in the particle colliders then look for the signature of these particles. Sometimes, the results of such experiments do not match theoretical predictions, sending theorists back to the drawing board to come up with a better explanation for the outcomes observed.

Godbole's work tries to discern the properties (like mass, charge and spin) of these elementary particles, some of which are yet to be found. Her research also helps experimentalists develop strategies to find evidence for the production of these particles in collider experiments and understand their formation in the Universe. As a member of the International Detector Advisory Group, Godbole had been invited to participate in the discussion on the design and concepts of the International Linear Collider (ILC), a next-generation particle collider. Her work has involved calculating the effects of photons produced at these colliders, some of which can cause disruptions to observations in the experiments at these colliders. Knowing how the photons behave can help machine designers block them or account for them when measuring other things in their experiments. Her work has also played a role in suggesting strategies used for hunting the elusive Higgs boson – a long-missing piece of the Particle Physics puzzle – and establishing its properties.

The search for Higgs boson



Computer simulation of particle traces from an LHC collision in which a Higgs boson is produced

According to the Standard Model, matter particles are the building blocks of matter, and force particles control them. So far, this model explains the interactions we see in nature and is consistent with all the observed phenomena. However, for a long time it did not explain how some particles like electrons and quarks (which make up protons and neutrons) have mass while others, like photons, are massless. With the Big Bang, which resulted in the Universe's formation, countless particles were created, all without mass. But soon after, something changed, and some particles began to gain mass. As a result, the quarks combined to form the first protons, then fusing with neutrons to create the atomic nucleus. Soon, an electron was trapped by the nucleus, resulting in the hydrogen atom and all the elements that we know today. So, how did particles begin to gain mass?

In the 1960s, François Englert and Robert Brout as a team and Peter W. Higgs independently put forward a theory that explained this mass-gaining phenomenon. They proposed that soon after the Big Bang, an invisible field called the Higgs field occupied the Universe. When particles interact with this field, they acquire mass, and those that do not interact (like photons), remain massless. Weakly interacting particles (like electrons) become light, while those that interact intensely (like some quarks and the force carrier particle W, Z bosons) become heavy. The Higgs field was fundamental to the formation of the Universe and all matter. If it were to disappear suddenly, all matter would instantly become massless and disperse at the speed of light!

But how do we know the Higgs field exists? For that, we need to detect the corresponding force particle, that is, the Higgs boson. Armed with the LHC, the largest and the most powerful particle collider in the world, scientists at CERN began to look for the Higgs boson with multiple experiments. On 4 July 2012, they made the long-awaited announcement. The detectors at the LHC had observed a new particle, which had a mass corresponding with the predicted Higgs boson. With their theory of how particles gain mass gaining confirmation through the discovery of the Higgs boson, Englert and Higgs jointly received the 2013 Nobel Prize in Physics.

The discovery of the Higgs boson has raised as many questions as it has answered! Scientists are investigating its properties to understand how it fits into the framework of the Standard Model. Currently, the ideas of the Standard Model explain what makes up the visible matter, which constitutes only a fifth of the Universe. A large part of the Universe contains dark matter, about which we know very little. Particle physicists at CERN are building better particle colliders to recreate the events following the Big Bang to catch a glimpse of the particles that make up our Universe, including dark matter.

Looking for a needle in a haystack

The work of a theoretical particle physicist like Godbole is akin to a detective investigating a crime scene. Physicists carefully look for footprints left by elusive particles, like the Higgs boson, produced only once in a trillion collisions. 'It's like finding a needle in a haystack. Just that the haystack can be a few kilometres wide in size,' explains Godbole. Since these particles quickly decay into their stable forms, hunting them soon after collisions is a colossal task that one person cannot accomplish. Hence a big community of particle physicists with mammoth detectors have been involved in this chase for the last few decades.

Theoretical physicists also help those who conduct experiments to identify new particles resulting from particle collisions. 'We help to paint the needle with a bright colour, so it is easy to find,' explains Godbole. One way to do that is to mathematically calculate the mass, spin and the other properties of the predicted particle and look for the one corresponding to this sketch. It's a great find if there's a match, but it's far more fascinating when there's none, for it could change the face of physics. The stakes of such findings are also high. The mass of the Higgs, for example, tells us a lot about our Universe and whether it can go up in flames after a few million years.

Godbole's work also investigates if the Higgs boson further decays into other particles that are not contained in the Standard Model and are perhaps 'invisible' to the 'eyes' of the experimentalists, namely, the detectors. Her work lays out strategies to look for their effect in the pile of particles in the collider. It also tries to interpret what such findings could mean for physics beyond what we understand from the Standard Model. 'What has happened so far is that, unfortunately, we haven't found that decay,' she says. 'I am investigating how the properties of the Higgs can tell me about the physics beyond the Standard Model.' Godbole is also excited about the new horizons that Particle Physics could touch with better detectors, powerful colliders and superfast computers entering the scene.

Sowing the seeds for the future of India's science

When Godbole returned to India after her PhD in 1979, she was the first woman to join the theoretical physics group in TIFR as a postdoctoral fellow and became part of the small community of particle physicists in the country. During her professional life, she had to make choices between her personal and professional aspirations without the necessary support structures that a woman scientist needs. Determined to change things for the better, Godbole now calls for better institutional support for women to excel in their scientific pursuits without having to compromise their personal dreams. In her role as a member of some of the government's committees focusing on women in science, she has been influential in bringing in many vital policy changes in this regard.

Godbole strongly believes that a successful scientist should also help to build science in the country through education, outreach and training. Practising what she preaches, Godbole has played many advisory roles in building the scientific infrastructure in the country to help India achieve its goals. She calls for the country to be part of global collaborations while also creating a training ground for young scientists to conduct cutting-edge experiments. One thing that plagues the scientific ecosystem in the country, Godbole says, is the lack of focused motivation and leadership among the country's scientists. 'After a short period, efforts get diffused,' she rues, citing her experiences. If we successfully tackle this challenge, the future is ours.

'A remarkable insight into some of the stellar work being done by Indian scientists ... makes for excellent reading.'
HASAN JAWAID KHAN, Chief Scientist, CSIR-NIScPR

'Written in such a simple style that even a layman would have no difficulty in understanding. Highly recommended!'
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'A very valuable book.'
Professor DINESH K. SRIVASTAVA, Homi Bhabha Chair Professor, National Institute of Advanced Studies

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WHAT ARE THE ORIGINS OF THE UNIVERSE?

HOW DO WE PERCEIVE EMOTIONS IN OUR BRAIN?

HOW CAN WE CREATE DESIGNER MOLECULES TO PROBE LIFE?

HOW CAN WE TAP INTO THE DNA'S REPAIR SHOP?

India has an amazing community of scientists doing cutting-edge work across their disciplines - from astronomy to neuroscience, nanoscience to botany. Who are they? And what are they doing? In this fascinating book, acclaimed CERN scientist Archana Sharma and science journalist Spoorthy Raman profile some of the most brilliant scientists working in the Nobel Prize-awarded fields of science and describe their work to us. Written for a lay reader, *India's Science Geniuses* makes the exciting world of Indian science come vividly alive.

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