Prof. Padmanabhan: A Personal and Professional History

Jasjeet Singh Bagla and Sunu Engineer

Prof.T. Padmanabhan (known to friends and students as Paddy) was born on 10 March 1957 in a lower middle class family at Trivandrum, Kerala, India. His mother, Lakshmi, was a home-maker. His father, Thanu Iyer, had a genius for mathematics but had to abandon his academic pursuits because of family circumstances and take up a job in the Forest department of the Government of Kerala. However, his father, as well as several other family members of his father's generation, had a great passion for all of mathematics, especially geometry. Two strong inspirations in Paddy's early life, which influenced him to take up academic pursuits, were his father and another senior member of the family, Neelakanta Sarma. Both of them had a high level of personal integrity and passion for knowledge — two qualities which Paddy inherited. Paddy recalls that the code of life emphasised in the family circles in which he grew up was simple: "*Excellence is not negotiable!*"

Given this background, it was no surprise that Paddy acquired a high level of expertise in mathematics — well ahead of what was taught in his school, the Government Karamana High School, Trivandrum, where he did his schooling in the vernacular, Malayalam medium — and developed a strong interest in geometry. Other than his mathematical abilities, Paddy was not a child prodigy of any kind; while he was within the top three students in his class all along, he was not even a consistent class topper in his school. (His major problem was the Hindi language, which was compulsory; he regrets that he still hasn't learnt it!) Another passion during his school days was chess, which also he learnt from Neelakanta Sarma. Unfortunately, even state level competitive chess needed devoting so many hours which he could ill afford, and, at some stage, he decided to pursue academics rather than chess — a decision about which he has occasional regrets even today!

After ten years of schooling (1963–1972), he joined the Government Arts College in Trivandrum for two years of the Pre-degree (1973–1974) as it was called then. Three major events occurred during this period, which, sort of, decided his future lifeline.

J.S. Bagla (✉) · S. Engineer
Department of Physical Sciences, IISER, Mohali, Punjab, India
e-mail: jasjeet@iisermohali.ac.in

J.S. Bagla and S. Engineer (eds.), *Gravity and the Quantum*,
Fundamental Theories of Physics 187, DOI 10.1007/978-3-319-51700-1_1

First, he came across the *Feynman Lectures in Physics*, and found Physics to be more fascinating than pure mathematics, which was the original career he was planning to pursue. “It appeared to me”, says Paddy, “that theoretical physics beautifully combines the best of objective science and the elegance of pure mathematics.” Though the Feynman lectures did influence his decision to change his mind as regards his career, Paddy is hardly a fan of Feynman as a person! In fact, other than influencing his career decision, the Feynman lectures did not figure in his physics education directly; he learnt the first round of physics from the 5 volumes of the *Berkeley Physics Course*, and later on from the 10 volumes of Landau and Lifshitz’s *Course of Theoretical Physics*.

Second, he came across a wonderful organization — and later became an active member of it — called the Trivandrum Science Society. “Thinking back, I find it hard to believe that such an organization existed and flourished, influencing a handful of us so strongly. It was a transient phenomenon, which lasted for just about a decade,” says Paddy. This was an organization entirely run by students in Trivandrum colleges, financed by membership fees and donations from well-wishers. Here, the members devoted themselves to the pursuit of science, unshackled by curricula and examinations. Paddy and a few others had an informal self-study group which concentrated on theoretical physics, and in a span of about 3 years, Paddy managed to master the volumes of the *Course of Theoretical Physics* by Landau and Lifshitz.

Third, Paddy took the National Science Talent Search (NSTS) examination organized by the NCERT, Government of India, which was probably one of the greatest stimuli that the government provided to students who wanted to pursue pure science. Success in this examination guaranteed a handsome scholarship for the rest of one’s scientific career, as long as one pursued pure science. The money was very important to people like Paddy, whose family’s financial position was never too good. In addition, NSTS scholars could participate in one-month summer camps at leading institutes in the country, allowing them to interact with researchers even while they were pursuing their college education. The Trivandrum Science Society also used to run “classes” to prepare students for the NSTS exam. These classes were run essentially by senior students and sometimes by one’s own contemporaries, but it was really a wonderful procedure for entrapment: “Whether one got through the NSTS exam or not,” says Paddy, “the classes made you realize that the pursuit of pure science is the best thing one can do. The indoctrination was done rather subtly but very effectively!”

After his pre-degree, Paddy joined the University College, Trivandrum for his Bachelor’s Degree (B.Sc, 1974–1977) in Physics. His final year of pre-degree and the first two years of B.Sc were again noteworthy in two respects. First, this was the time when he worked through the Landau-Lifshitz volumes and various other books in theoretical physics, spending sometimes 14 hours a day in this pursuit. He also acquired a fascination for anything related to gravity and was strongly influenced by the epic book *Gravitation* by Misner, Thorne and Wheeler (Freeman and Co.). “This book was an eye opener for me; I am probably one of the few people who have worked through every problem in this book. I still have hundreds of pages of handwritten notes I took from this book, since I could not afford to buy it — and xeroxing was unheard of in the seventies in Trivandrum!" says Paddy. The second key event, which has nothing to do directly with his academic pursuits but shaped his entire attitude towards life, was his exposure to Upanishads, Zen philosophy, meditation techniques, etc. (This is not directly relevant here, since this article is mainly about Paddy's academics; his homepage contains two articles with a clear description of these aspects.)

The mastery of theoretical physics, especially General Relativity (GR), helped him to publish his first technical paper in GR in 1977 when he was still a B.Sc student. He started working seriously on several ideas in GR and quantum field theory around this time. Paddy was a Gold Medalist for topping the B.Sc exam in Kerala University, and joined for his Master's in Physics (M.Sc) in the same University college. Given the fact that he already knew all the standard stuff which was taught in the M.Sc course in Physics, he had sufficient spare time for his research work. The interaction with the other members of the Science Society was very helpful in these academic activities.

Needless to say, Paddy was again a Gold Medalist for topping the M.Sc. in Kerala university in 1979. By now, he had caught the attention of several leading scientists both in India and abroad. The NSTS summer camps (at IIT, Kharagpur and the Raman Research Institute, Bangalore) as well as an Einstein's Centenary Symposium (1979) at PRL, Ahmedabad which he attended, helped significantly in this regard. Pursuing a Ph.D in the US or the UK (like some of his close friends in the Trivandrum Science society did) would have been a logical course to follow, but his family circumstances prevented him from doing so. As a result, he decided to join what was then probably the best research institute in the country (and an internationally acclaimed one), viz., the Tata Institute of Fundamental Research (TIFR) for his Ph.D. He joined TIFR in August 1979 and became its tenured faculty member (called Research Associate, which was the entry-level faculty position in those days) in February 1980, while still working towards his Ph.D. His thesis work was in Quantum Cosmology (done under the supervision of J.V. Narlikar) and he got his degree in 1983. This work developed a particular formalism of quantum cosmology which had the potential to solve the cosmological singularity problem - an idea which echoes in many of the currently fashionable quantum gravity models. His thesis also contained the notion of the wave function of the universe, which was being developed independently by Hartle and Hawking around the same time, from a different perspective.

During his Ph.D years, he met and fell in love with Vasanthi (who was also a research scholar, one year junior to him, in TIFR). They got married in March, 1983 when he had just completed his Ph.D and Vasanthi was still pursuing hers. Vasanthi's entry into his life had a strong influence in - amongst other things - his academic pursuits. She was working under the supervision of Ramnath Cowsik on the nature and distribution of dark matter in the universe. Paddy found this area fascinating and started collaborating with her in this subject. This broadened his interest into several aspects of astrophysics - an interest which has continued since then - and resulted in his entering the area of cosmology, in which he later made his mark.

Prompted by this new found passion, Paddy decided to take up a research associate position at the Institute of Astronomy, Cambridge for one year (1986–1987) rather than go for post-doctoral work in his thesis area. He was strongly influenced during this time by Donald Lynden-Bell, whose scholarship and breadth of scientific interests resonated well with his own way of doing science. He found the subject of the Statistical Mechanics of Gravitating Systems particularly fascinating, and spent a fair amount of time working on different aspects of it. His own contributions to this area are highlighted in the first single-authored review he wrote for *Physics Reports* in 1990 and the later lecture notes of the prestigious *Les Houches Schools* in 2002 and 2008. His authority in this subject is well recognized not only by the astrophysics community, but also by the condensed matter community interested in the statistical mechanics of long range systems.

Interestingly enough, he started supervising two students (T.R. Seshadri and T.P. Singh were the first two) just after finishing his own thesis. The steady flow of students continued — in spite of him being rather selective — and he has so far supervised the thesis work of sixteen students. It is commendable that ten of them hold faculty positions in different institutes in India and are guiding their own students. At present his academic family tree has forty grand-students! “I can take no credit for the achievements of my students, except to say that I did not spoil them”, says Paddy, “I was fortunate because good students always wanted to work with me. In the early years, when my age gap with the students was moderate, Vasanthi and I maintained very close personal contact with them and they were like members of our family. It was wonderful.” In fact, almost all the young ($\lesssim$ 45 years) cosmologists working in various institutes/universities in India today have been associated with Paddy and mentored by him in the Ph.D/post-doctoral stage of their career, in one way or another.

Another facet of Paddy’s career, which also took root during his TIFR days and flourished in the years to come, is his public outreach involvement. In addition to the numerous popular lectures he gave, Paddy became a regular contributor to two science magazines of India (the *Science Today* and the *Science Age*) which existed at that time. He ran several regular columns in these magazines, like *Playthemes* (on recreational mathematics), *Let us think it over* (on everyday physics applications), and *Milestones in Science* (on the history of science). His strong interest in the history of physics prompted him to present the *Story of Physics* as a comic strip serial in the *Science Age*. This was extremely popular, and, later on, was published as a book, translated into several Indian regional languages and made available to the school children at an affordable price. This was made possible, in large part, because Paddy does *not* take any royalties from this work. More recently, he ran a 24 part serial in the science journal *Resonance*, called the *Dawn of Science*, dealing with the history of all sciences, from pre-history to the 17th century. A popular science book which he wrote, *After the first three minutes* [2000; Cambridge University Press (CUP)] has also been very well received and was translated into Portuguese, Chinese and Polish. Paddy remains strongly committed to the responsibilities of scientists towards the society, and continues to be very active in public outreach programmes.

Around 1990, Paddy started working on his first single-authored book, Structure Formation in the Universe (CUP 1993). He was persuaded to write this book by Martin Rees, who introduced him to Rufus Neal, the CUP commissioning editor.

This book was extremely well received and made Paddy well known among the astrophysics and cosmology community. Since then, Paddy has taken to writing books like a duck to water, and has published 9 more — with a few more in the offing! “Recently,” Paddy recalls, “Martin Rees commented that he had triggered a run-away process when he persuaded me to write that first book!”

People often ask him how he manages to write so many high-quality books while keeping up with his research, and maintaining an average of more than 8 research publications per year. “Well, you need two things”, says Paddy, “first, you need the discipline to work on it 2 hours each day – in which you can write 6 pages, if you have everything ready in your head. So, a 600 page book will just take 100 days. But, of course, you won’t have everything in your head, so it will take about 5–10 times more time; so you can turn out one book every 2–3 years. The second thing you need is Vasanthi. She worked with me in all the books, taking care of much of the typing, latexing and back-end processing!” Every one of his books acknowledges Vasanthi’s contribution.

In 1992 he shifted from TIFR to the Inter-University Centre for Astronomy and Astrophysics (IUCAA). During the early part of his career at IUCAA, he concentrated on various aspects of structure formation in the universe. Along with his Ph.D student, Jasjeet Bagla, and later on with Sunu Engineer, he developed a code which describes the dynamics of a large number of (of the order of a few million) astrophysical particles, which is known as an N-body simulation code. *This code was the first of its kind in India at that time*. “What took nearly 3 weeks to compute with the best computers available to us in those days, is being done in half an hour with a laptop today; but it was fun developing the code from scratch, bringing in as much innovation as possible,” says Paddy.

Coming from a theoretical physics background, Padmanabhan’s perspective on astrophysics was rather different from that of many other people whose initial training itself was in astrophysics. In particular, he noticed that there was no comprehensive treatise covering all of astrophysics, like, for example, the Landau–Lifshitz course for theoretical physics. He was lamenting about this to Jerry Ostriker, during his visit to Princeton in 1996, when Jerry asked him “Why don’t *you* write it?” During the next few weeks, Jerry was very supportive and helpful in making concrete the structure of a 3-volume *Course of Theoretical Astrophysics* which Paddy came up with. These 3 volumes were published by CUP during 2000–2002 and reviewers have called them magnificent achievements. With these, Paddy became well known to a very large community of astrophysicists and his breadth of scholarship was recognized all around. More recently, he wrote two graduate level textbooks, on *Gravitation* (CUP 2010) and on *Quantum Field Theory* (Springer 2016) with which he has covered almost all the frontiers of theoretical physics and astrophysics.

One reason he could write so many books is his passion for innovative teaching. Paddy strongly believes that research and teaching should go hand-in-hand. He has taught virtually every aspect of theoretical physics and astrophysics at the graduate schools in TIFR and IUCAA, in addition to occasional courses at the Pune University and IISER, Pune. He is considered a fantastic teacher and his lectures on even routine topics are punctuated by creative and original approaches — something which echoes in his books, which elaborate on his classroom teaching. At present, he has started on designing a course for senior undergraduates which will teach them *all of* theoretical physics in about 150 lectures. This course will eventually appear as a four-volume text book.

While completely at home with any aspect of theoretical physics, Paddy's real passion is for quantum aspects of gravity. He never let go of this, having tasted blood in the early years of his career. From the early part of 2000, he decided to spend more time in this area, with his astrophysical interests taking a back seat. Given the importance and potential of this work, a detailed description will be appropriate:

The two most important conceptual advances in theoretical physics, made during the twentieth century, were General Relativity and Quantum Theory. However, all attempts to put together the principles of these two disciplines have repeatedly failed, often after a lot of hope and hype which accompanied each attempt. The research work of Paddy, over the last decade or so, suggests that this is because we have misunderstood the nature of space-time structure, and are applying the principles of quantum theory to the wrong physical entity.

An analogy will make this clear. A fluid, or a solid, is described by certain mathematical equations in classical physics. Applying the principles of quantum theory directly to these equations will allow you to discover what are known as 'phonons' – the microscopic quanta of the vibrations of a solid. But this approach will never get you to the atoms, which are the true basic constituents of the solid. To obtain the correct description, you first need to recognize that matter is made of atoms, and then apply the quantum principles to these atoms.

The key new insight provided by Paddy's research shows that the status of space-time, in General Relativity, is completely analogous to the status of a fluid in classical physics. There is a sufficient amount of *internal* evidence — uncovered by his work — to indicate that space-time, itself, is made of more fundamental and microscopic degrees of freedom, which are analogous to the atoms in a solid. This means that applying the principles of quantum theory directly to Einstein's field equations — which is what almost all models of quantum gravity attempt to do — will inevitably lead to failure. Paddy's research allows one to identify, and *actually count* these degrees of freedom (which is similar to counting the number of molecules in, say, one litre of a fluid). It is then possible to apply well defined principles of statistical mechanics to describe the dynamics of these degrees of freedom, and show that the result, in the appropriate limit, leads precisely to Einstein's theory. Further, his research allows one to extend these results towards a broad class of theories far more general than Einstein's theory, showing that Einstein's theory is just one special case of a much deeper paradigm.

Every good paradigm shift should allow us to recognize the key theoretical problems from a deeper, more fundamental perspective and thereby solve them. Paddy's approach is no exception, and it gives fresh insights into solving the following problems:

- Observations tell us that the present-day universe is composed not only of the normal atoms we see around us, but also an exotic type of matter called dark matter, and another component termed as dark energy. It is very likely that this dark energy is equivalent to what is known as the cosmological constant – which was a term that Einstein introduced into his equations. The numerical value of this constant was a mystery, and was considered to be *the* key problem in present-day theoretical physics. Paddy's approach shows how the value of the cosmological constant can be naturally related to the amount of *information* which an observer in the universe can access, and predicts a mathematical formula to determine its value. The numerical value predicted by Paddy's work is in perfect agreement with cosmological observations!

This work also makes a *falsifiable prediction* — which is more than any other approach to quantum gravity has done — about the very early, inflationary phase of the universe. This prediction is also borne out by all present-day cosmological observations and future observations can test this with greater precision.

[Incidentally, part of this work was done in collaboration with his daughter, Hamsa Padmanabhan. Born in 1989, to two parents with Ph.Ds in astrophysics, she grew up in the academic atmosphere of the campuses of research institutes. While the parents encouraged her to pursue whatever she wanted — and she had a taste of arts and literature — she could not escape the charming world of science and ended up as the third Ph.D in astrophysics in the family!]

- Paddy's approach allows one to understand several peculiar features of gravity, including the thermodynamic behaviour of black holes, from a natural and broader perspective. That is, the microscopic picture based on the atoms of space-time allows us to understand almost all the features of macroscopic, classical gravity in a simple and intuitive manner. Again, this has wide-ranging consequences going well beyond the realm of Einstein's theory, which no other model has achieved so far.
- A second key problem in theoretical physics concerns the origin of the universe, as well as the ultimate fate of the collapsing matter which forms a black hole. While Paddy's approach has not yet completely solved these deep issues (together known as 'the singularity problem'), it sheds light on the way forward towards the final resolution of these problems. With the development of a novel mathematical framework to address the properties of the microscopic nature of space-time, Paddy's approach has the potential to address the singularity problem in a direct and elegant manner. Thus, it has made further advances than any other approach in the literature, towards the resolution of the deepest problems in theoretical physics.

It is fair to say that our understanding of gravity underwent a fundamental paradigm shift in 1915, with the advent of Einstein's General Theory of Relativity. One hundred years down the line, we are poised on the brink of another breakthrough, with the novel paradigm shift led by Paddy's research.

Another feature of Paddy's career – which again sets him apart from many other scientists in his peer group – is his willingness and capability to provide scientific leadership in various ways. He has served in several key committees and has taken a leading role in the development of astronomy in India. Here are a few examples from the recent years: (a) The Department of Science and Technology has appointed him as the Convener of the Advisory Group (2008–2010) to facilitate India's entry into one of the international collaborations building the next generation Giant Segmented Mirror Telescopes. He has played a key role in taking this initiative and developing a consensus in the Indian astronomy community in this task, which has now led India into joining the TMT. (b) He served as the Chairman (2006–2009) of the Time Allocation Committee of the Giant Meterwave Radio Telescope (GMRT), has introduced many innovative aspects into its working and been instrumental in streamlining several aspects of the GMRT. (c) He was the Chairman (2008–2011) of the Indian National Science Academy's National Committee which interfaces with the activities of the International Astronomical Union. In addition to advising the Government on policy issues, this also required him to coordinate the International Year of Astronomy 2009 activities in the country. In the international arena, he was the President of the Commission 47 on Cosmology of the International Astronomical Union (2009 – 2012), and the Chairman of the Commission 19 (Astrophysics) of the International Union of Pure and Applied Physics (2011 – 2014).

Paddy has received numerous awards and distinctions in India and abroad for his contributions. He is an elected Fellow of all the three Science Academies of India as well as of the Third World Academy of Sciences. The national and international awards received by him include the Padma Shri (2007), the J.C.Bose Fellowship (2008-), the Inaugural Infosys Prize in Physical Sciences (2009), the Third World Academy of Sciences Prize in Physics (2011), the Millennium Medal (2000), the Shanti Swarup Bhatnagar Award (1996), the INSA Vainu-Bappu Medal (2007), the Al-Khwarizmi International Award (2002), the Sackler Distinguished Astronomer of the Institute of Astronomy, Cambridge (2002), the Homi Bhabha Fellowship (2003), the G.D.Birla Award for Scientific Research (2003), the Miegunah Award of the Melbourne University (2004), the Goyal Prize in Physical Sciences (2012–2013), the Birla Science Prize (1991) and the INSA Young Scientist Award (1984). His research work has won prizes from the Gravity Research Foundation, USA seven times, including the First Prize in the Gravity Essay Contest in 2008.

Paddy is unique in his breadth of scholarship and his passion for knowledge. Few scientists in the world – and no one in India – is so competent and knowledgeable in a wide spectrum of areas ranging from the numerical analysis of astrophysical data to the realm of quantum gravity! While reviewing his book on Gravitation, one reviewer actually chose to comment on the author by saying, ".... *There is immense erudition, and mastery of both formal tools and calculational details; it is really* *impressive that one individual can understand so much, so deeply ....*", a feeling echoed by many who have closely interacted with Paddy.

Personally, Paddy feels that theoretical physicists are a fortunate lot. In a preface to a recent book, *Sleeping Beauties in Theoretical Physics* (Springer 2015), he makes his view quite clear: "Theoretical physics *is* fun. Most of us indulge in it for the same reason a painter paints or a dancer dances — the *process* itself is so enjoyable! Occasionally, there are additional benefits like fame and glory and even practical uses; but most good theoretical physicists will agree that these are not the primary reasons why they are doing it. The fun in figuring out the solutions to Nature's brain teasers is a reward in itself."