Interview

Of Mind and Matter: Interview with Sumathi Rao

Sumathi Rao giving a talk at HRI around (c. 2009–2010). Sumathi Rao

Sumathi Rao is a theoretical physicist presently based at the International Centre for Theoretical Sciences (ICTS-TIFR), Bengaluru. Her research lies primarily in the domain of condensed matter physics. Prior to this, she was a long-standing faculty member at the Harish-Chandra Research Institute (HRI), Prayagraj (formerly Allahabad), where she served for fifteen years. Prof. Rao received her doctoral degree in particle physics from the State University of New York at Stony Brook.

In this interview, Prof. Rao reflects on her early years in Vadodara, her formative experiences at IIT Bombay, her time at SUNY and the friendships, her engagement with art and music, and her journey through the world of science.

Purnima Tiwari: How would you describe your childhood? Did you always have an inclination towards Science?

Sumathi Rao (top row, second from the left) with her school friends in 1973 (Class XI). Sumathi Rao

Sumathi Rao: When I was a child, I was always interested in logic and puzzles. I used to read a great many detective stories and was fascinated by the process of finding things out. During the final years of high school, I happened to come across one of the volumes of the *Feynman Lectures on Physics*. Although I did not understand many of the concepts at the time, I found the book to be extremely well written and was deeply interested in reading it. That was how I gradually became interested in physics during high school. The language of the lectures was also quite compelling. Since I was interested in English literature at the time, Feynman's lectures struck me as a work that was not only elegantly written but also rich in scientific content, which greatly appealed to me.

PT: As you have mentioned that you liked reading detective stories, did you ever think, as a child, that you would be a physicist in the future?

SR: No, when I was younger, I wanted to be a detective—like many kids, I suppose, at that time. Alternatively, I wanted to be a writer, but that was also when I was very young.

PT: What were the early influences on you? You mention that you were mostly interested in detective stories. But apart from that, were there any forms of music, arts, or sports that you explored on your own or with others during your childhood?

SR: I come from a South Indian family, and we were all taught Carnatic music as children—it was an integral part of our cultural upbringing. That was primarily during my early childhood. Later on, of course, we all used to listen to Hindi music.

I was fortunate to grow up on a campus, and we used to play badminton every evening. I participated in tournaments and even won medals—during that time and throughout my years at IIT as well. In Gujarat, where I lived back then, there were not many women in sports, so we had greater opportunities, especially because we lived in the IPCL (Indian Petrochemicals Corporation Limited) colony. That gave us access to many facilities, and we even went to Anand (of Amul fame) to witness state-level and national-level badminton matches. Some of us also participated in state-level competitions at that time. In addition to badminton, table tennis was quite popular in our colony, and we used to play that regularly. These activities were mostly outside of school—organized within the colony. The colonies were small and inclusive, so both boys and girls played together. That was beneficial for us, I believe, because growing up with such mixed participation improved our games and our confidence.

Aayush Verma: So you belong to a South Indian family? Then who in your family moved to Gujarat?

"I cannot go to sleep unless I read a novel at night. A novel, meaning something that is not science."

SR: My dad was working at IPCL, so that is why I lived in Gujarat. I was born in Hyderabad, and for six years, my dad was in London. So we were also there, and then later on, we came back to Hyderabad. When I was about twelve, we moved to Vadodara. So my early childhood was in Hyderabad, and then later in Vadodara. And my dad was always interested in puzzles and logic, so he would give us books like those by *Martin Gardner*. That is another book I remember that we read. Mathematical puzzles, logical puzzles—those were all fun things to do.

PT: You seem to have a keen interest in English novels. Can you possibly list a few which are your favorites genres? And have you continued your reading journey in terms of novels thus far?

SR: Well, right now, the only thing I continue to do—which has been, and I think will continue to be, with me all through my life, even when I have been extremely and completely involved in science—is reading. I cannot go to sleep unless I read a novel at night. A novel, meaning something that is not science.

Fictional reading has always remained; it has always existed in my life. Over the years, my tastes have changed. Now I read a lot of Indian writers as well, which I never used to read earlier. Even now, on campus, in our colony, I belong to a book club. Everyone picks books to read, and once a month or so, we meet to discuss them.

PT: Can you list a few of your favorites?

SR: My early favorites used to be authors like *Jane Austen* and others similar to her. That was when I was in college and for many years afterward, because I still think she is one of the excellent writers. And then, all the old classics—like *[Charles] Dickens* amongst others.

But now, what I read is not all those things. I continue to read a lot of detective stories, which are probably a staple. I read science fiction too. *The Three-Body Problem* is a recent, fantastic novel in that genre. In detective novels, there is one that combines detective fiction and science fiction—*The* $7\frac{1}{2}$ *Deaths of Evelyn Hardcastle*. Have any of you read it?

PT: I am mostly into classics and contemporary fiction and nonfiction.

SR: In the recent Indian authors in contemporary fiction, I like *Amitav Ghosh*. And *Rian Malan* is another one of the writers I like. He is from South Africa, and pens some unusual literary accounts. I'm right now living in Bangalore, so I probably should read *Bano Mushtaq*, which I have not read yet. *Salman Rushdie* is another great favorite of mine, and I have read most of his books. So those are the kinds of books that I like.

AV: What are you reading currently?

SR: Right now, I am just thinking about what the most recent book is—the one I've been reading with the book club in our housing colony. It was —again, a science fiction novel: *Recursion* by *Blake Crouch*.

And if you're really asking me what the latest book I've read is—well, it's something I came across recently. I had gone to my sister's house, and we were all looking through our old books, which included one that I had received as a prize. It happened to be by *Alistair MacLean*, from my school days. I don't know if any of you have read Alistair MacLean—it's probably way too old now. Some of those books were later made into movies: *The Guns of Navarone, Fear Is the Key*—these were all adventure books from the time when I was in school. I like re-reading old books.

Devang Bajpai: You chose physics over engineering, right? Do you think that, back then, it was a good decision, or would you want to reverse it?

SR: Yes, actually. I chose physics over engineering, and it was not a particularly difficult decision for me, because my parents were quite okay with it. I think in those days—this was about forty or fifty years ago—my parents were comfortable with me studying anything. They were not overly concerned about how I would earn my living, and so on.

In those days, I think that if it had been a boy who wanted to study physics rather than engineering, there would have been more pressure to change the course. My brother, who is almost ten years younger than I am, took engineering. My younger sister, who is two years younger, also took engineering.

My father wanted one of us to pursue medicine, but we were all very squeamish and did not like medicine at all. So we all ended up in science and engineering. So yes, it was a very good decision in retrospect. Engineering was also interesting at that time. My sister went into computer science, and that was a different kind of life. But I think, in retrospect, it was the right decision for me.

AV: Did you write the JEE exam?

SR: I did not write the JEE exam. However, I was offered direct admission to a five-year IIT programme, because at that time, I was an NSTS (National Science Talent Scholar) and also a rank holder in my board exams.

AV: And you did not choose to go there?

SR: No, I did not choose to go there. At that time, I was very homesick. I had originally planned to go to IIT Bombay, but later I changed my mind and decided to pursue a B.Sc. at MS University in Baroda (currently Vadodara).

DB: Did you have any physics heroes when you were young?

SR: I would say *Feynman*, probably—simply because his Lectures on Physics was the physics textbook that I loved. I think I first came across Volume 3, which is Quantum Mechanics.

AV: Was this in high school when you picked up Feynman? Did the teachers recommend you?

SR: Class 11 or 12, , I think—that is when I was reading Feynman. It was not part of my school curriculum. And once I got the National Science Talent Fellowship, from then on, every year I used to buy some books—some *Scientific American* old volumes, collected issues, etc. At that time, more than textbooks, it was popular science that attracted me. While pursuing my B.Sc., I had a very good physics teacher named *Prof. J. S. Bandukwala* at the Maharaja Sayajirao University of Baroda, which was a small university. Undergraduates were taught by the university professors themselves. There were no associated colleges, because Baroda is a very small town. So the university professors directly used to teach us, and if some student was interested, they themselves used to take a lot of interest.

"I would say Feynman, probably—simply because his Lectures on Physics was the physics textbook that I loved."

There were a couple of people—one was *Prof. Madhuben Shah* from Berkeley, and I forget where Prof. Bandukwala did his Ph.D., but he was a very inspiring teacher. His office was always full of students, he would still tell us stories about the Los Alamos atom bomb project, Oppenheimer, etc., among other things we would not otherwise come to know of. I think those things were very nice and motivating.

Then, for my M.Sc., I went to IIT Bombay, where our class had a large number of girls. So we had a very nice batch where we could discuss things. And once you go to IIT, I think things become streamlined. Everybody would apply to go abroad for a Ph.D., and you would do what your seniors did. But the decision to go to Bombay—and this was more than forty years ago—for all of us, not just for me, required parental approval. All the other girls who came also had to be allowed by their parents to be away from home and pursue their careers. This was, comparatively, much less common than it is now. It is probably still uncommon.

AV: I also wanted to ask you: which part of physics excited you the most in those days, especially when you were finishing your Bachelor's and moving into your Master's? And why did you choose IIT Bombay?

SR: In Baroda, I read a lot of popular science, and many of those things had to do with particle accelerators and so on. So yes, pursuing particle physics was my aim when I went for my master's.
And IIT Bombay was a choice because it was the closest to home—as simple as that. I remember that there was a clash in dates for the IIT Bombay and the IIT Kanpur exams, and I chose IIT Bombay.

AV: Were you clear about doing particle physics during your Bachelor's?

SR: Yes, I would say that. Although, I did not have a lot of knowledge, I had the feeling that I wanted to pursue theory rather than experiment. So, if someone asked me, I would always say particle physics. It sounded like the most exciting area to me—finding out what things are made of.

Some people were more excited about astronomy, but I was always inclined toward asking: what is it made of? Going deeper and deeper, breaking things down, and trying to understand their fundamental constituents—that always appealed to me.

AV: Do you think that happened because particle physics was mainly in the news at that time? Because every day something was coming up in these accelerators that the general audience was also interested in?

SR: Yes, I think so. I didn't even know if something was happening every day, but a lot of the popular science articles made it sound that way. But of course, everyone follows fashion. I think it had more to do with that than anything else—not that we really understood it deeply. And that is true even of the students who come today. Many of those who want to study string theory don't really know about it—they just know that it's very exciting.

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Yes, so with particle physics—it sounds exciting, right? That you get to know what things are made of at the deepest level.

AV: And what was your master's thesis then at IIT Bombay? What did you work on?

SR: I worked on something called 'neutrino–antineutrino oscillations'. It falls within particle physics. This area involves extremely light particles that do not interact electromagnetically; they interact only via the weak force. At the time I was working on it, it was believed that neutrinos were massless. It was much later—sometime around 2000—that it was discovered they do, in fact, have a very tiny mass. So, neutrino oscillations were a major topic of interest back then, and that is what I worked on for my master's.

AV: So after that, you decided to move to Stony Brook in the USA. How did you choose to go there? Did something in particular attract you to that place?

SR: Yes, one of my seniors, *Neelima Gupte*, who was a year ahead of me, had gone there. And basically, the way it worked in those days was that you applied to places that did not ask for application fees. First, you would send what were called "pre-apps" to about twenty places, and then you would send full applications to four or five universities.

You chose universities based on the advice from your seniors and professors, and you would get to know about the places where you might have a good chance and which did not ask for an application fee. So, Stony Brook did not have application fees, and hence a lot of Indians went there at that time. Sometimes, you would apply to one high-profile university like Princeton, just for the possibility. I have forgotten where I had applied for a high-level place, though. I think I had gotten into Stony Brook and one more place, which was maybe the University of Illinois Urbana-Champaign.

There were not many choices, and there were several of us who were applying from my class. So we would also try to divide up the places so that not everybody applied to the same place. Also, since our teachers had to write many recommendation letters, each of us would typically apply to about three or four places, to avoid overburdening them. That was how it was done back then.

AV: What was the Department of Physics at Stony Brook like during your time there?

SR: Stony Brook had a very strong Department of Physics back then. There were many faculty members, and the particle physics group was particularly active. By that time, I had already decided that I wanted to do my Ph.D. in particle physics.

C. N. Yang was there, working on parity violation, and he was the head of the Institute for Theoretical Physics. I remember, in our very first semester, all of us went to sit in on his course on gauge theories. We were not registered for it, and we did not understand much, but everyone just wanted to see him and listen to him speak. A lot of the names that you would read in books and papers—when you see them, you'd get very excited—so that was what happened. Also, at that time, Stony Brook had a very good Indian representation. There were five Indian students in the senior batch, five in mine, and another five or so in the next batch. Altogether, the department had about twenty Indian Ph.D. students, which created a strong and supportive community.

AV: Among the students from Stony Brook, how many eventually returned to India?

SR: A large fraction of the Stony Brook students did come back. Compared to most of the other universities, I think quite a few of us returned to India.

AV: Could you share your personal experience of your time at Stony Brook?

SR: I think the time you influence each other the most is during the IIT years or the Ph.D. years. In my case, it turned out to be the Ph.D. years which created an enormous difference in my life. I think all of us influenced each other a lot. All of us used to like reading books. We used to talk about other things besides physics—like politics, etc. Sometimes it happens a little earlier for some people. That is, for some, the most formative years are the IIT years. But for me, I would think my Stony Brook years were very formative. That's where I met, of course, my husband, *Ashoke Sen*, also. We learned a lot of physics from one another—apart from what the faculty taught us formally. There was a great deal of informal learning. Because we would have lectures and classes, then we'd go out for dinner, then all of us would go back to our offices in the Institute—and work, play, discuss, everything together, as we lived in the dorms then.

Sumathi Rao (in the center) with Ashoke Sen (top-left) and friends from SUNY. Sumathi Rao

AV: Was Prof. Sunil Mukhi at Stony Brook at the time as well? And were Prof. Rohini Godbole and Prof. Aparna Dar there too?

SR: Yes, Sunil Mukhi was there. Rohini Godbole had already left before I joined. Aparna Dar was there, but she was in the Mathematics Department. Neelima Gupte, Ghanashyam Date, and Ranjan Ghosh were also there.

Many of them came back to India—Date came back, Ranjan came back, Neelima came back. Sunil, Ashoke, and I came back too. Very few people stayed abroad.

AV: Many physicists and mathematicians have historically gone abroad after their master's degrees. Why do you think this was the case? Why did people choose to pursue their Ph.D. overseas? Do you think the situation is any different now? Are more people staying back in India for their post-graduation studies?

SR: I think more people stay back now, because there are many more places in India. It didn't even occur to us to do a Ph.D. in India. Places like TIFR were considered elitist, so we didn't really think about them. And there was not much discussion about TIFR or IISc in those days.

I had a very good friend in IIT who wanted to stay back in India, *Chayanika Shah*—she did her Ph.D. at IIT Bombay, and she is now a well-known feminist and LGBTQ activist. And then there was somebody else from my class named *Prajval Shastri*, who did her Ph.D. at the JAP programme in Bangalore, in astrophysics.

But unless people had some reason to stay back in India, the general idea was to go abroad. There was a one-time investment—the amount of money you had to put in for the ticket—which was large, and getting a visa and a ticket to the U.S. was not easy for most middle-class families at that time. But you could somehow manage it. Then afterwards, everything was on scholarship. The scholarship money you received was sufficient to live there reasonably comfortably, and we could come back to visit India occasionally.

"Science, of course, is universal—it is an international subject. There is no such thing as national physics or anything like that."

Whereas in India, the Ph.D. stipends—although they existed—would not have been sufficient, perhaps. But we never really thought about it. The idea back then was that science was something which was done abroad. I think that has changed now, because there's a lot more science being done in India.

And the institutes that were prominent in those days, like the IITs, were not known for research—they were simply supposed to be good teaching institutes. So it didn't occur to us that one should stay back for a Ph.D. I certainly think things have changed now, but still, there are a large number of visiting students here at ICTS as well, who come here to pursue their master's thesis, and a large fraction of them do want to go abroad.

And to be honest, I think there are advantages to doing that. Firstly, science, of course, is universal—it is an international subject. There is no such thing as national physics or anything like that. And you do learn a lot by seeing the world and meeting very different kinds of people. Many people go abroad simply to 'grow up'. One way of saying it is that by leaving home and going abroad, they learn to fend for themselves.

Sumathi Rao with Robert Shrock, his wife I-Hsiu Lee and their child in late 90s when Rao was visiting SUNY. SUMATHI RAO

DB: How did you come in contact with Robert Shrock, and what work led you to choose him as your Ph.D. advisor?

SR: *Robert Schrock* taught us a course in Particle Physics. He was young at the time and had just started teaching. These things happen somewhat organically—you try to choose appropriately from the available options. I mean, there was another new faculty who had come in that semester called *George Sterman* whom

Ashoke and some other students approached. But I was keen on working in particle physics, and I wanted someone whom I could approach easily and who might take me on as a student.

I had done reasonably well in his course, so I thought it was worth trying. Also, at that time, he was working on neutrino oscillations, and since I had worked on neutrino oscillations for my master's thesis, I thought I might have some background on the topic. But actually, I ended up not doing my project in neutrino oscillations, but rather in something called 'neutron-antineutron' oscillations. This was a topic related to the Grand Unified Theory (GUT). Around the early 1980s, there was considerable excitement around unifying the fundamental interactions. The weak and electromagnetic forces had already been unified in the 'Weinberg–Salam' model[1], and people were exploring whether the strong interaction could also be incorporated into a single framework. And in this grand unified theory, protons were supposed to decay. In India also, people looked for the proton decay in the Kolar Gold Fields. There's a very famous experiment in the Kolar gold field where they claimed that the proton did decay. And it turned out to be wrong. Nevertheless, it triggered a wave of interest and several conferences were held on GUTs and baryon number violation.

Now, in the case of neutron–antineutron oscillations, the process involves a violation of baryon number (B) by two units, instead of the single unit in proton decay. Since the neutron is a neutral particle, such an oscillation is theoretically allowed. In terms of the quark model[2], a neutron consists of udd, and an antineutron would be $\bar{u}\bar{u}\bar{d}$. So, one could, in principle, have a transition of a neutron into an antineutron, analogous in structure to neutrino oscillations. And you could think of a neutron oscillating into an antineutron in the same way that you would think of neutrino oscillations.

However, this process would require $B - L$ (baryon number minus lepton number) violation, not just baryon number violation. That was my Ph.D. thesis. We calculated how such oscillations could occur, what the possible mechanisms were, what the decay channels would look like, and what experimental signatures one might expect and how would they oscillate? Those kind of things.

Neither proton decay nor neutron oscillations have been observed so far. But if they do occur, they would do so only at very high energy scales.

AV: All of the work you've been describing—was it within the framework of Grand Unified Theories?

[1] See: **1**. Glashow, Sheldon L. "*The renormalizability of vector meson interactions.*" Nuclear Physics 10 (1959): 107-117.
2. Weinberg, Steven. "*A model of leptons.*" Physical review letters 19.21 (1967): 1264.
3. Salam, Abdus, and John Clive Ward. "*Weak and electromagnetic interactions.*" Il Nuovo Cimento (1955-1965) 11 (1959): 568-577.

[2] There are six quarks which make up the matter: up (u), down (d), top (t), bottom (b), charm (c), strange(s).

SR: Yes, all of that was within the framework of Grand Unified Theories. Now, of course, people do not focus only on Grand Unified Theories. The attention has shifted. I think many are working on quantum gravity.

I think in the late 1980s, string theory (a theory of quantum gravity) began to gain prominence—particularly because it aimed to unify not just the three gauge interactions but also gravity. Quantum gravity became more mainstream than GUTs at that point.

AV: You transitioned from working in theoretical high-energy physics to condensed matter physics. What motivated this shift, and how did it shape your overall research?

SR: That shift happened quite late, when I was a faculty member at the Institute of Physics in Bhubaneswar. During my postdoctoral years, I was still working in theoretical high-energy physics. At Stony Brook, my work was more phenomenological—closer to experiment. When I moved to Fermilab, I continued some of that phenomenological work, but also began engaging with more theoretical aspects of quantum field theory.

In particular, I worked on something called the topological Chern–Simons theory. That was part of what I did during my Fermilab years.

AV: How did you get interested in this?

SR: How I got interested in that was, again, as often happens—through others around you and what they are working on. A more senior faculty member or a senior postdoc can influence these directions. Some of the work was influenced by my office-mates.

As a Ph.D. student, you are typically given a project, but as a postdoc, you must look for your own projects and collaborators. At Fermilab, one of the researchers was working on topological field theories, so I started working with him. That's how I got interested in the subject. We discovered some interesting identities at the time, and while I moved on to other things, the work would become relevant again much later when I started working on the quantum Hall effect in condensed matter physics. At that time, that was the end of it, and then I started working on other things.

Once I came back to India, I started working on particles called *anyons*, which are intermediate between bosons and fermions. These anyons turned out to be connected to the quantum Hall effect, a subject in condensed matter physics.

"How I got interested in that was, again, as often happens—through others around you and what they are working on."

Earlier, in high-energy theory, my focus was on understanding particles as isolated objects. We would ask: what happens when two particles collide? How are particles created from the vacuum? These were the kinds of questions particle physics addressed. But quantum field theory teaches you that the vacuum itself is not empty—it is a dynamical medium, more like a liquid with fluctuations. You might think of it as a sea with virtual particles bubbling in and out of existence. So even the so-called vacuum is a many-body system. It's not a single-particle theory. The kind of theories that are needed to describe even single particles are actually quantum field theories.

Condensed matter physics is basically about many-particle systems. The only difference now is that the total number of particles is finite. If you take a table, for example, it has a definite number of atoms. Whereas in high-energy physics, the vacuum can, in principle, support arbitrary numbers of virtual particles. So once you make the number of particles finite, the same kinds of quantum field theories can be applied to condensed matter systems.

So what happened was that many of these topological field theories started being applied also to condensed matter systems, like the quantum Hall effect. And then there was one of my fellow students from Stony Brook, *J.K. Jain*. He happened to be working on the fractional quantum Hall effect, and he came up with a new idea called composite fermions. And I saw those papers. I happened to see those papers through a reference in works by the very famous particle physicist *Frank Wilczek*. Since I knew J.K. Jain, I started reading his papers and found that they were interesting, very elegant and very nicely written. So that was how I transitioned from high-energy physics to condensed matter physics.

I should mention that after returning from the U.S., there were some years when it was quite difficult to find a conducive research atmosphere. We did not have the same ecosystem here that I had experienced abroad. For a time, I struggled to find meaningful projects. But in the long run, I found that condensed matter physics offered many interesting and feasible research directions.

PT: Continuing with your time at Fermilab—how was pursuing a postdoc in the U.S. Midwest for you?

SR: My postdoc years were actually quite difficult in the U.S., especially at Fermilab. It is not a university—there are no students there—and postdocs are the youngest, the lowest in the academic hierarchy. There are some other postdocs, of course, but not nearly as many as you would find at a university. And without students around, you are not part of a larger group—you do not have that anonymity that comes from being one among many. So it was difficult.

I was the only woman, and there were just a few Indians. We were in the Midwest—in Chicago—and we did not know very many people there. Until then, I had always lived a very 'student' kind of life—always in a group, always surrounded by friends.

At Fermilab, besides Ashoke and me, there was one more Indian student, *Sumit Das*. I had an office-mate, *Terry Leung*, who was from Hong Kong, China, and we became friends. But still, Fermilab was very different from Stony Brook. It was a lot of hard work, and it was difficult to keep up with all the senior people, and even with the Indian postdocs like Ashoke and Sumit. They always seemed one step ahead. They found things easy—I did not. But that always happens, right? You always come across people who are better than you. So I had to work very hard. That is just how it was.

Until then, for me, work had been easy. That is the point. It always happens, I think—at some point, you hit your limit, and then you must push yourself.

PT: You have spoken before about how, during your time in the Midwest, your experience was shaped by both your gender and your background. While many Indians at the time may have felt out of place due to gender expectations in science, you have mentioned feeling doubly out of place—due to both your gender and racial identity. Could you tell us more about how that shaped your experience?

SR: Yes—wrong color and wrong gender. So I ended up extremely scared to speak up, and I always thought that I would say something stupid. So basically, I kept my mouth shut throughout those years. But then, you are also judged for keeping your mouth shut—that is the irony, right? I mean, you have to participate. Otherwise, you are judged. Yes, you are judged by your papers, of course, but you are also judged by how much you contribute to discussions. So it was difficult. Those were real difficulties. But yes, one learns.

"And then you realise that it's not that difficult, it is possible."

PT: You mention that you were always scared of saying something wrong or something stupid. That is something very prevalent among students, especially when transitioning from high school to a university environment or beyond.

SR: Yes, I was always very quiet. But until a certain point, you could get away with being quiet. I would only talk among peers or with close friends. Even at IIT, I was terrified to speak up in class, and I would never open my mouth. But it didn't matter much back then. At Stony Brook too, I didn't have to speak much publicly. I was very poor at giving seminars—at IIT, I was terrible at it.

But eventually, I had no choice—I had to give seminars. And then I had to give multiple seminars in order to get my next postdoc. Until the first postdoc, my advisor's recommendation was enough. But for the second one, I had to travel around and give 20 to 30 talks at different universities across the country. Those were really difficult times. But you have to do it—so you do it. And then you realise that it's not that difficult, it is possible. I mean, you have to give seminars, you have to answer questions that people ask you—it's not easy, but it's possible.

AV: So would you encourage younger students to participate in these activities as early as possible?

Sumathi Rao receiving the APS fellowship from Smitha Vishveshwara, chair of APS condensed matter division in March 2023. Sumathi Rao

SR: Yes, I would suggest to younger students that they participate as early as possible and get over their fears as quickly as they can. In my case, it happened very late.

AV: Because in academia, you're supposed to eventually do these things, right?

SR: Yes, exactly. You have to go around, give talks, defend your theories, ask questions—that's how research works. These things are difficult. I've had to speak with people, try to get involved in projects. When you are young, you have to be the one to take the initiative, to ask. In my case, because I wasn't doing that much, one of the senior people stepped in and asked someone else to at least check if I was interested in a project. So, at Fermilab, people did notice and help me out, but still, I had to do a lot more. That is eventually the learning experience.

DB: You have done your work in quantum transport and mesoscopic systems. What excites you most about this field today?

SR: Right now, what I work on is something called *topological quantum matter*.

Think of the difference between a donut and a sphere—that is the kind of distinction we are talking about. So, actually, what I work with involves such topological distinctions—like knots and unknots, or two inequivalent knots. These are purely mathematical in origin, but they arise naturally in the systems we study.

In the kinds of materials I work on—these are materials, crystalline in the position space—what happens is that in momentum space, the wavefunctions of the electrons, say $\psi(k)$, belong to different topological classes. You can compute topological invariants like *Chern numbers* or winding numbers by integrating these wave-functions or functionals of these wavefunctions over the Brillouin zone[3].

Now, what people discovered is that the wavefunctions in momentum space can have non-trivial topological structure. Until around the early 2000s, people did not know that such topological phases even existed. In condensed matter, we were used to classifying phases of matter as solids, liquids, gases, magnets, etc., using Landau's theory. Landau gave us an entire paradigm where phases were described through spontaneous symmetry breaking and local order parameters.

But around 2000, people realized that there is a completely different way to classify matter—based not on symmetry breaking, but on topology. So in the last twenty years, this has led to a complete overhaul of what is now called the Landau paradigm. We now classify certain phases of matter by topological invariants rather than local order parameters.

Many standard materials turn out to be topologically trivial, but there exists a whole class of new materials which are topologically non-trivial. These are characterized by non-zero Chern numbers or winding numbers. So, metaphorically, instead of a sphere (which is topologically trivial), these materials are like donuts or tori—they carry such topological information.

Initially, these materials were predicted theoretically, and then later discovered experimentally. And now we know of many such topological materials. We have also realised that the quantum Hall systems are actually topological phases, but they need very strong magnetic fields and very low temperatures, whereas the new topological materials can be discovered or in fact, specifically designed. What is especially exciting is that in these new materials, we are not just dealing with electrons in the usual sense. Even though we're not talking about elementary particles, you still have quasiparticles—collective excitations—that behave differently. In fact, what people have found is that you can get fractionalized particles which are quasiparticles. The fractional quantum Hall effect was the first such phase to be discovered.

Now, in certain systems, people have started looking for Majorana modes—quasiparticle excitations that are their own antiparticles. These are extremely exciting because of their potential application to topological quantum computation. Right now, Majorana modes

[3] [SR] If you have a crystal, there is periodicity in real space. Because of that periodicity, when you go to momentum space—essentially a Fourier transform—the momentum values are quantized. So there are only a finite set of independent momenta and then the values repeat. This periodic momentum space is called the *Brillouin zone*.

are what everyone is looking for. Microsoft, for instance, has claimed they have observed them. They have announced something called the Majorana-based qubit, and published some of their work in Nature. But the community is still skeptical because their data is not fully reproducible, and being a private company, they cannot release all experimental details. Until at least one independent group reproduces their results, there will be doubt.

So that's where the field is now. These materials are exciting both for fundamental physics and for potential applications to quantum technology. Recently, I have also been looking into generalizations of Majorana modes—something called parafermions. That is what I have been working on lately. And yes, it is very exciting. Hopefully, some of these developments will soon enter the mainstream.

PT: How did your association with IUPAP begin? And what motivated you to get involved with its mission?

SR: Actually, I was asked by *Nandini Trivedi* from TIFR. She had been asked by someone she knew—*Judy Franz*—but Nandini was leaving India at that time and going back to the U.S.. She and her husband had stayed in India for a few years, and then they went back. She wanted someone from within India to try and collect feedback from Indian women physicists on whether they had faced any discrimination in their careers, and so on.

So, in my first round, I was asked to give a questionnaire to about thirty women physicists, and send that collection back to IUPAP. They were doing this globally—in all countries. So from India, I became the person who was asked. There was no systematic way of identifying anyone to do this—it just happened by chance. Since I knew Nandini, she asked me.

When we first gave this questionnaire, it was interesting to see that most of the women said that they hadn't faced discrimination in their careers up until then. Although each of them mentioned problems, they thought that it was personal to them. But this is not the kind of feedback you would get now, if you were to send out such questionnaires to women in India.

There have been many instances since then where people have said they've been discriminated against at various levels. But I think what happened in the early years was that there were so few women that we simply did not think about it, or thought it was personal to us. We just decided to ignore the sexist remarks, ignore the discrimination of any kind, and sort of blot it out. People in our generation also just assumed that casual sexism would happen—and we took it to be normal.

PT: So was there a committee appointed to send out the questionnaire and collect the responses?

SR: No, at that time, there wasn't. It was all self-organized. Nandini asked me, and I did it. Then I started talking to Neelima, Rohini [Godbole], and all these people—the whole Stony Brook gang. For the first IUPAP meeting, there was some ambiguity about who should go.

There were five people whom they could support from India, so they asked me to suggest names. Then they asked if there was anyone who could be considered a kind of "success story" from India, and I suggested Rohini.

It was all very informal in the first round because we didn't have an organization. I think we should have reached out to something like the *Indian Physics Association*, but none of us were even members at the time. So there really was no formal structure—it was just people talking to each other.

Now all these things are much more systematic. But back then, the number of physicists in India itself was quite low compared to today. There were very few research institutes in India at the time, right? Besides TIFR, there was IISc, then IMSC in Chennai, the Institute of Physics in Bhubaneswar, and HRI was new. Then there were the IITs, where a few people did research. And universities, where some research was happening—but not much. The newer IITs and the IISERs were yet to be established.

PT: Would you say that the idea for Lilavati's Daughters was somehow inspired by this initiative from IUPAP?

SR: When the IUPAP initiative came up, Rohini was at IISc at the time, and she was elected to the Academy of Sciences. They had decided to create a committee or a subgroup for women, and she became the president of that. Once she took over, things became much more formalized. I think she had a lot more clout—and she was already quite well-known in the field of particle physics. So she could get many more people involved.

By then, I was in Allahabad, which was quite far away from all this. So, the only way I was involved was by initially writing to people. After that, the main momentum shifted to Bangalore. I continued with IUPAP for a few more years, and then Shobana from Bangalore took over, and later Prajval Shastri. Gradually, many more people became involved.

In the first few rounds, we didn't even know how to reach out to people. I remember in the third round, someone from Tatanagar wrote to me, saying she was interested. The second meeting was held in Brazil, the third in South Korea—and then it really started to broaden. People from Delhi and other places also got involved. For the first meeting, which was in Paris, everyone's travel and stay were covered by IUPAP. But from the second round onwards, we had to write to various institutions and agencies to raise funds so people could attend. We especially wanted students to go, so that meant trying harder to arrange support. Once Rohini got involved with the Academy of Sciences, she was able to help. Many of the women did not have travel support and travel money, particularly younger ones.

PT: What does working as an editor in a research journal look like? Could you describe the duties and responsibilities of such a position, and how has the experience been for you overall?

SR: The duties and responsibilities of a Divisional Associate Editor (DAE) at *Physical Review Letters* (PRL) are quite specific. The day-to-day editorial operations are taken care of by the journal's staff. But the role of the DAE becomes important once a submission enters the peer review process.

Each submitted paper is sent to at least two referees for review. As a physicist, you regularly receive such referee requests yourself from various journals, so you know how the process works. The referees send in their reports, which are then forwarded to the authors. The authors respond to the comments, and there's usually a fair bit of back-and-forth—revisions, clarifications, rebuttals.

Now, when there is a conflict between the referees—say, two recommend acceptance and one recommends rejection—then the entire correspondence, including referee reports, author responses, and editorial notes, is escalated to the DAE. As the DAE, you have access to the identities of both the authors and the referees, although the referees remain anonymous to the authors. Your job is to carefully read through all the material and make a judgment: should the paper be accepted or rejected?

This is not always straightforward. You have to assess whether the referee comments are fair, whether there might be a conflict of interest, or if someone is being unnecessarily harsh. You have to evaluate whether the criticisms are scientifically justified or perhaps overly stringent.

In most cases, the decision made by the DAE is accepted by the editorial board. There is someone even above the DAE—an Editor-in-Chief—but in my six years in that role, I've never had a case go beyond me. The decisions I made were accepted, and the authors, even if unhappy, generally did not escalate further. And we also, as editors, normally try to uphold the referee's comments. Referees volunteer their time and thought, and we don't want to undermine that work. So unless a referee is clearly wrong, or being too demanding, we try to support their recommendations.

AV: Among your Stony Brook friends, I know that many, like Prof. Sunil Mukhi and Prof. Aparna Dar, have a deep interest in music. Do you also share that inclination? Do you listen to music regularly?

SR: Yes, I do listen to music, though not as seriously as them—Sunil and Aparna are very dedicated listeners. My engagement is far more modest. But my family has always been musically inclined. Both my parents played musical instruments—my father, who is no more, and my mother, who can't play anymore. But my mom is still terrifically interested in music, and that is probably what is keeping her in good spirits.

They were both very fond of Carnatic music—South Indian classical music. So, naturally, I grew up around it. When I was in Allahabad, I used to try learning classical music from a local teacher, perhaps once a week. And now that I'm back here in the South, I still try to continue—though it's rather sporadic—through online classes with a teacher who is also a friend of my mom's. I do like to sing, although it has not been very consistent.

AV: Do you enjoy Carnatic or Hindustani classical music?

SR: When I lived in North India, I used to listen to and also try to learn North Indian classical music, but I would say that I like Carnatic music more. I also enjoy Hindi film songs. I like *ghazals*, *bhajans* and lighter music, but at the classical level, I much prefer Carnatic.

DB: Physics often demands sustained focus over long periods of uncertainty. How do you personally sustain motivation during times when results are elusive or ideas remain unresolved?

SR: I'd say that my motivation largely comes from the people I engage with—especially my students. I hang out a lot with my students, and they are very enthusiastic. That's what gives me my enthusiasm as well. In recent years, I've found that many of the questions they bring to me have become a primary source of my own curiosity and drive. That interaction keeps me engaged.

There are also a few topics—like Majorana fermions and other emerging areas—that naturally capture my interest. Topological quantum computation is also new and is something I am interested in. Even AI, machine learning—all these things are new and they interest me, at least to the extent that I want to understand what people are talking about. But to actually get to work on these things—it's really a lot of hard work, and that, I don't think I'd be able to do unless I have students around me who are motivated, who go deep into the nitty-gritties and ask me questions so that I'm forced to get into the details. If I were by myself, I think I would only do superficial reading.

Four academic generations: Sumathi Rao; her student P.K. Mohanty; his student Urna Basu (SNBNCBS, Kolkata); and her two students and her two students.
Sumathi Rao

DB: How was Bhubaneswar for you, and how was physics like back in the day?

SR: Bhubaneswar was where I started my career as a fully independent scientist, and I enjoyed my time there. It felt like a continuation of my student life. I used to interact mainly with PhD students at that time, not so much with the faculty, because I was staying in the student hostel—as they didn't have housing for me. So I continued staying in the hostel, along with the students I used to teach, actually. I would take their classes, but I would also live with them. So in that way, it was a very different atmosphere from what most people have. Teachers usually live in separate quarters from students. Even in IITs, the teachers have their own housing, even if it's within the same campus—or in places like HRI. So in that sense, it was quite different.

I was still trying to figure out what I really wanted to do. At that time, I hadn't yet moved into Condensed Matter Physics—I was still doing High Energy Physics. Those were the years when I was trying to explore what direction to take, what would really interest me. The only thing I was sure of was that I did not want to do String Theory. In my final year in the U.S., I had also tried to learn String Theory because it was fashionable then.

"Some students tended to judge women faculty more harshly and wondered whether I was really confident about my lectures."

There were also some difficult aspects of being in Bhubaneswar. One issue was the people I met in Orissa at that time, who were mostly Bengali, and many of them had very strong opinions. They were more sexist than others I had encountered. They were not used to having women faculty members, and I was the first woman faculty there. So those kinds of issues did arise, and it made the initial years of teaching a bit difficult. I also wouldn't say I was very good at teaching in the beginning. I probably did not know the level at which I was supposed to teach, and so on. There were some very good students, some of whom became my best friends later. But I think some of the students also tended to judge women faculty more harshly and wondered whether I was really confident about my lectures and work.

But overall, except for one or two such negative elements, the experience was nice. It was also initially hard to get PhD students, because they had to trust a female faculty member to be able to guide them, and that took some time. So I think I got my first official PhD student quite late—just around the time I was moving to Allahabad—and he moved with me. That was *P.K. Mohanty*. He was very smart and has done really well. He became faculty at the *Saha Institute of Nuclear Physics* in Kolkata and is now a professor at IISER Kolkata.

Before that, a couple of other unofficial students had worked with me for their PhDs, but they were registered under other people. *Dattu Gaitonde*, who worked with *Prof. S. N. Behera*, had done a lot of his PhD work with me.

AV: Was Dileep Jatkar also your student? And what paths did your other students take?

SR: No—during his [Jatkar] PhD, four of his papers were with me, but he wasn't officially my student. He worked with *Prof. Avinash Khare* for his PhD, but we wrote papers together. He was very smart, and I was looking for people to collaborate with.
At that time, we were working on Chern-Simons theories. He [Jatkar] wrote four papers with

With collaborators and students. Includes Yuval Gefen, Ganpathy Murthy, Sourin Das, Arijit Kundu, Arijit Saha, Adhip Agarwala and others. Sumathi Rao

me during his PhD. But when he went to TIFR as a postdoc, he moved into string theory. *P.K. Mohanty*, my first official student who did his PhD with me, also went to TIFR for his postdoc. He switched fields as well—he started working with *Deepak Dhar* and others there. So he completely moved into statistical mechanics, a different area.

The first of my students who stayed in the same field I was working in was *Sourin Das*. He is currently at IISER Kolkata. He works on mesoscopic physics, and we continue to collaborate even today.
Actually, a lot of people I have worked with are now in IISER Kolkata—P.K. Mohanty, Sourin Das, and *Siddhartha Lal*, a student of *Diptiman Sen*, with whom also I have collaborated.

AV: So, the longest of your employment has been at HRI? What decision brought you there after Bhubaneswar?

SR: Yes, I was there for 25 years. The main reason was that *H.S. Mani* offered both me and Ashoke [Sen] jobs at the institute. At the time, we were living at two opposite ends of the country, but he brought us together—right in the middle—by offering us both positions. He was starting a new institute then, and that's what made the move possible. So yes, that was the main reason. It was called *Mehta Research Institute* back then.

AV: And how was Allahabad for you?

SR: Allahabad was fantastic for us—I loved it. That's where I spent all my working years, and we always felt that the Institute was ours. From the very beginning, we were there and were involved in everything. There was a whole group of us—mostly in our early or late 30s—and together, we built the Institute from scratch. We started the graduate school, began teaching, even turned on the computers ourselves. The campus really became our life. We would often tell people, this is real India—you must come and visit here, not just Bombay or Bangalore or Goa.

So there's a deep sense of belonging and achievement—we felt personally attached to that place. And the students felt it too. Older students often say that what made HRI special was this sense of community. If you talk to any HRI alumni, they'll almost always say they think of the Institute as their home. Many of them would love to go back—they really loved their years there.

AV: Did you ever teach or have any employment at IIT?

SR: I have not taught at an IIT as a faculty member. But I have given colloquium talks at IIT Kanpur, and I have many friends there. One of my Master's students is now a faculty member at IIT Kanpur, and I know many people there. I like IIT Kanpur a lot.

AV: Do you like Uttar Pradesh as a state? Have you been to the Kumbh(s)?

SR: Many of us loved UP. We felt that this was where we belonged. And yes, of course—I've been to the *Kumbh*. HRI is located right on the Kumbh grounds. We attended the 2001 and 2013 Kumbh Melas, and the Ardha Kumbh in 2007 and 2019. We just missed the 1995 Ardha Kumbh.

AV: Oh! And the recent Maha Kumbh?

SR: No, not that one. It's become very commercial now. Back then, it was really lovely—we could just walk down from our institute to the Kumbh grounds.

There's something called the *American Physical Society* (APS) March Meeting, where around 10,000 people come together. It runs for a whole week, with several parallel sessions, from early morning till late at night. You go from session to session, talking to people—some sessions are excellent, some are quite bad—but there's always something going on. You just keep moving around, soaking it all in.

Usually, the Kumbh Mela used to be like that. I mean, there would be several tents, and there were people giving bhashans. You can call them talks, seminars, whatever you wish—they were about spiritual matters. Every tent would have some of these sadhus giving these seminars, and people would be sitting around, listening. Some tents would be extremely crowded—they reminded me of those APS meetings when graphene had just been discovered, and it had become the rage in physics. And then there were tents that were barely attended. But people would just be walking around, exploring everything.

A lot of those who came to the Kumbh were simple villagers, coming from different parts of

Sumathi Rao's artworks.
Left: An oil painting done in the 1980's. Right: A recent pencil sketch of a little girl.
Sumathi Rao

the country. In 2001 and 2013, it wasn't very politicized. So it was much, much nicer—more like a genuine gathering of people who simply wanted to witness and be part of something extraordinary.

AV: I believe the very original intention behind the Kumbh Melas was just that—a space for dialogue, correspondence, and debate.

SR: Yes. Now it's very different. But back then, it was really more of a spiritual gathering. I guess it was just fun to walk around and see the diversity—so many different kinds of people. Even in 2013, several foreigners came—even to HRI. We used to warn them: Don't come on the major bathing days—you won't be able to manage the crowds! I remember a couple—maybe from Israel—they showed up with their backpacks, walked through the entire mela, and came all the way to the Institute from the station, just like that.

PT: I was just curious—are there areas outside of physics, besides literature, such as philosophy or art, that inspire you or feed your creative thinking? I know you prefer oil paintings in particular. Could you tell us what makes oil painting so special for you?

SR: Actually, at Fermilab, when I was very frustrated with my work, I started going for some art classes—and in fact, I started going for oil painting classes—so that is one reason I got very interested in oil paintings. At that time, it was just for relaxation from whatever else I was doing, but what I found was that the teacher was good, and oil painting is easier than other kinds of painting because it is more forgiving. If you make a mistake, you can wait for a while and paint over it, and you cannot make it out at all—you can change things and just wait and repaint. That was one reason I used to like oil painting back then.

But now, I actually do much more sketching than painting, because sketching takes less time, and sometimes you can finish it even in a day. But I do want to get back to oil painting, which maybe I'll probably do once I get some more consistent time. Since we have recently moved to Bangalore, it has been very busy. Relocating from Allahabad to Bangalore—with bag and baggage—took a lot of time.

When we were in New York during our PhD, we went to many of these museums in Stony Brook—the Metropolitan Museum, the Museum of Modern Art, the Pierpont Morgan Museum, etc. We would spend several weekends like that. This was part of the Stony Brook gang that I was talking about. We used to go to the city and see these things. And then later on in life, we got lucky, and we managed to stay in Paris for a year on a sabbatical—I think it was in 2000—and then we travelled around in Europe. We witnessed a lot of this really fantastic art. In Europe, when you go around, you see that it's not just the museums—sometimes even the old buildings, the churches—many of them have beautiful art on them.

PT: The architecture there is art in itself, actually.

SR: Exactly, yes! The architecture there is art in itself, so you really get interested in that.

I think, as a kid, I was always interested in drawing, but I never took it seriously—never thought I could actually do it—until my postdoc years. So each of these things has its own reason. I think music, art, and all these things often offer an escape from your work when things are not going well, but then they also become interesting in their own right.

PT: We often ask what advice you would give to the younger generation, but instead, may we ask: what is one piece of advice you think they should not take?

SR: I think one thing you should stay away from is people who tell you, "This is what you should do to get ahead," or "Go do this to be successful." Because when somebody gives you advice on how to become successful—or whatever they say—they're actually defining success for you, and that just shouldn't be done. So I think you should stay away from anybody who tells you that this is the way to do things.

I mean, you should find your own way to do things, and you should find your own meaning—you should define your own success. In simple words: **don't allow someone else to define success for you**.

This interview was conducted remotely over a virtual meeting platform.