Udupi Ramachandra Rao (1932–2017)

Prof. U. R. Rao, internationally renowned space scientist and father of the satellite programme in India, passed away on 27 July 2017 at his residence in Bengaluru. Rao symbolizes several personalities – a versatile space scientist, a technologist par excellence, a passionate space application protagonist, leader, manager, institution builder, visionary – all rolled into one. He laid the foundation for the development of satellite technology in India, and is rightfully considered as the Father of India's satellite programme. India's capability of building world class satellites is largely due to his dynamic and visionary leadership. Though Rao will be remembered primarily for developing from scratch satellite technology in the country and putting India at par with other space-faring nations, he led the space programme in various capacities with unstinted commitment to align the goals of the organization with national development.

Udupi Ramachandra Rao was born on 10 March 1932 to Lakshminarayana Acharya and Krishnaveni Amma in Adamaru village, Udupi, Karnataka. He had his early education in Christian High School, Udupi and inter-junior course in Veerashaiva College, Bellary. He studied his B Sc at the Government Arts and Science College, Ananthapur under Madras University; and got his M Sc in Physics from Banaras Hindu University, Varanasi in 1953.

He started his career as a lecturer in physics. His passion for science prompted him to find avenues for carrying out research. In those days study of cosmic rays, discovered by Victor Hess in 1912, was an exciting field in particle astrophysics. The cosmic ray spectrum contains particles with energies as high as 10^{20} eV or more which cannot be produced in the laboratory. Study of these particles gives new information on particle interactions at these high energies. The discovery of cosmic rays also posed a number of questions – how do cosmic rays reach such high energies?; where are the natural accelerators?; what are the sources of primary cosmic rays?; – which are some of the challenging problems still not fully resolved. The study of cosmic rays and the nature of their interactions during their propagation from the source to the point of detection also could be used to get a better understanding of the interstellar and interplanetary medium. Young Rao was excited about understanding these challenging problems. In his own words '*The great scientists R. S. Krishnan and G. N. Ramachandran offered me 200 rupees scholarship for Ph D under them. Dr Sarabhai offered me 100 rupees. But I went to Ahmedabad and (to work with) Dr Sarabhai because I was interested in cosmic rays.*' He joined Physical Research Laboratory (PRL) in 1954 as a

An young Rao testing a sounding rocket payload.

doctoral student under Vikram Sarabhai. For the study of diurnal and semi-diurnal variations of galactic cosmic ray intensity he was awarded Ph D from Gujarat University in 1960. He then continued his research work at the Massachusetts Institute of Technology (MIT), as a post doctoral fellow and worked with Bruno Rossi's group at MIT who were studying cosmic showers. Rossi was an excellent physicist and experimentalist. Working with Rossi gave Rao good insight into instrumentation building for particle detection. Later Rao moved to Southwest Center for Advanced Studies at Dallas (now University of Texas) as Assistant Professor. The expertise gained at MIT was fruitfully used to build satellite payloads. During his stay at Texas he worked on several space missions such as Mariner-2 (the world's first successful interplanetary spacecraft), Pioneers-6, 7, 8, 9 deep space probes and the Explorer 34, 41 satellites. For these space missions Rao along with his colleague K. G. McCracken, designed and developed particle detectors to measure the degree of anisotropy of cosmic radiation in the energy range 7.5–90 MeV/nucleon with an accuracy of better than one part in 10^4. These studies resulted in deep understanding of the solar cosmic ray phenomena and the electromagnetic state of interplanetary space. Working on these space missions also gave him a good understanding of satellite technology.

Rao returned to India in 1966 and joined PRL and along with his colleagues, Kasturirangan, Prakash Rao and others, carried out extensive work in high energy astronomy, particularly on the correlation between the time variation of optical and X-ray emission of X-ray sources in the energy range 2–20 keV using balloon, rocket and satellite-borne instrumentation. Rao and his group also made significant contribution to the understanding of cosmic X-ray and gamma ray background and studied the effects of celestial X-ray sources on the ionization of nocturnal-D-region ionosphere.

Sarabhai was looking for a leader to take the responsibility of developing satellite technology in India and the responsibility was assigned to Rao. The activity was started as a division – Satellite Systems Division – in the Vikram Sarabhai Space Centre (VSSC), then called the Space Science and Technology Centre (SSTC). The initial plan was to develop a 40 kg satellite compatible with the Scout launch vehicle of the USA and carry out some scientific experiments to build indigenous capability for building satellites. In the meantime there was an offer from USSR to launch a satellite developed by India on a Soviet launch vehicle. The task of realizing the satellite and associated activities was called 'Indian Scientific Satellite Project (ISSP)'. In August 1971 a team led by Rao was deputed to USSR to discuss and finalize the details of a joint satellite programme. As the story goes during the discussions with the Soviets they initially suggested that since satellite technology is complex, India should go step by step. Their advice was first to make only a satellite payload and put on a Soviet satellite. However, Rao was clear what he wanted to achieve. He insisted that India will

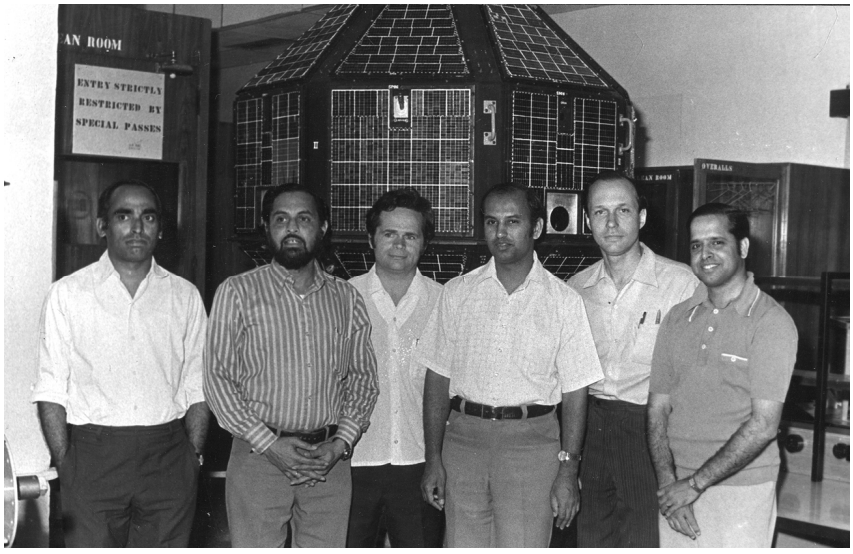
start with designing a complete satellite. But for his insistence, India would have lost the lead in satellite technology at least by a decade. This is typical of Rao – a long-term vision and never compromise on what he wants to achieve. It was realized that considering the academic and industrial environment, Bangalore was a better place compared to Trivandrum to carry out the satellite and the project was shifted to Bangalore. The project had to start from 'scratch' with no laboratory place, no man power, and no equipment! The activity started in the industrial sheds at the outskirts of Bangalore, a village called Peenya. Most of the scientists/engineers joined were fresh from college. In fact except Rao none in the initial team members had even seen a satellite, but they were competent, dedicated professionals with a focus to realize the project in time, meeting the quality standards. Apart from availability of trained manpower, many components required for building the satellite have to be procured from abroad. Rao could convince the bureaucrats that for a project like this where both time and quality of the product were of paramount importance, it is necessary to think 'out of the box' management techniques. Rao could persuade management to constitute special teams to go to USA and Europe to procure components and equipments required for the project. This is just one example of Rao's management style to get what he wants circumventing all odds.

The schedule given to Rao to complete the project was 30 months. It was a very tall order. It seemed an impossible task to do all this, including testing the satellite's ability to function in space, install ground control systems, etc. With his dynamic leadership, his technical foresight and above all his ability to motivate young minds, India's first satellite *Aryabhatta* was delivered in 36 months. Rao should be complimented for creating an organizational culture and work ethos which motivated these 'novices' starting from 'zero base' to go on to develop technologies, laboratories and test facilities for a technology which was new to the country. This was Rao's first big milestone in ISRO. Undoubtedly what he achieved is something very unique in the annals of our space programme.

Rao's focus was always how quickly the benefits of space can reach the common man, as envisioned by his mentor Vikram Sarabhai '… we must be second to none in the application of advanced technologies to the real problems of man and society'. Even before the launch of *Aryabhatta* he was planning to have the next satellite with focus on application and India's first remote sensing satellite – *Bhaskara 1* – was borne, which is the forerunner of the state-of-the-art remote sensing series of satellite IRS and Cartosat. Another bold step he took was to accept the offer from ESA to launch a geostationary satellite on the third experimental launch of the Ariane launch vehicle. Though the schedule was very tight, he took the challenge as it provided a low-cost opportunity to develop indigenous capability to carry out an end-to-end geostationary satellite communication programme. Thus the first communication satellite – APPLE – was born which can be considered as the forerunner of INSAT series of multipurpose satellite. As the number of satellites increased, it was decided to build a more permanent place and the ISRO Satellite Centre (ISAC) was born with Rao as its founder director. ISAC is the nerve-centre of India's satellite programmes. The new entrants to ISAC, working with the state-of-the-art equipment and test facilities in well-laid out buildings, may find it difficult to imagine that ISAC had a humble beginning in industrial sheds.

Rao should also be credited for the way he brought in the project management structure for ISRO's satellite projects. He introduced the matrix management structure for optimally utilizing the expertise across the various ISRO centres ensuring decision-making at decentralized level where technological proficiency lies. At the same time, to ensure adequate coordination, interface control, quality assurance and professional documentation appropriate management structure was created. Over the years, this basic organizational structure envisaged by Rao largely remained the same in the management of ISRO's space projects.

In 1984 Rao took charge as Chairman, ISRO, and Secretary, Department of Space and guided the space programme for 10 years. During this period he accelerated the development of rocket technology, resulting in the successful launch of the ASLV rocket in 1992 and completed the development of PSLV launch vehicle, which is currently the workhorse of ISRO for launching satellites in the polar orbit. Rao also initiated the development of the geostationary launch vehicle (GSLV) and the development of cryogenic technology. His chairmanship at ISRO can be described as the operational phase of India's space programme, when all experiments that were being tried out under Satish Dhawan's chairmanship became operational. He has been promoting the use of space technology for broadcasting, education, meteorology, integrated mission for sustainable development (IMSD), drought monitoring, disaster warning and many more. What was really unique about Rao was that apart from his dynamic leadership and institution-building capacity, he had a quick and deep and intense understanding



Rao (third from the right) and K. Kasturirangan (extreme right) with the visiting Soviet Engineers with *Bhaskara* satellite in the background.

of technology. He was a good physicist, and through physical laws, he understood many things on engineering side. In this process, he could really question engineers when he reviewed their work. By all accounts, Rao is a decisive, no-nonsense personality who took quick decisions and this trait of his has been evident throughout the development of India's space programme.

Even after retiring from ISRO, he took keen interest in the space programme and guided space activities as required. As Chairman of Advisory Committee on Space Science (ADCOS) he guided the space science programmes like Mars mission, *Chandrayaan-2*, solar monitoring mission (*Aditya*), etc. He has more than 350 publications in reputed journals and authored a number of books. His contributions to the nation extended beyond science and technology by guiding the Government of India in various capacities as part of the National Security Advisory Board, the Central Board of Directors, Reserve Bank of India and many more. His recommendations to the All India Council for Technical Education (AICTE) have become the primary force in shaping Government policies on technical education and other related issues in India.

His concern how space technology can be used for the welfare of the society transcended beyond the narrow confines of our county's boundaries and he took keen interest in reaching out to the other developing countries towards reaping the benefits of space technology for their national development. Recognizing this he has been offered a number of important positions in the international arena including Chairman of the UN committee on Peaceful Uses of Outer Space and Vice President of the International Astronautical Federation.

For his life-long contribution to space science, technology and applications, Rao had been bestowed with many national and international awards and accolades; elected as fellow of many reputed academies and institutions; awarded honorary doctorates by a number of universities and many more which are too many to record here. However, we shall mention two of the recognitions he got in the recent past. For his lifelong exceptional and distinguished service to the nation, the Government of India honoured him with the *Padma Vibhushan* in 2017. He is the only Indian who is inducted into the IAF hall of fame for his outstanding contributions to development of space technology in India and for his relentless efforts towards sharing the greater benefits of space technology with developing countries and the world at large.

Rao will go down in history as an inspirational leader par excellence with forthright views, innovative ideas and speedy actions, with his driving mantra 'if others can do, we can do better'. These traits of Rao should continue to be a motivational force and a role model for many young aspirants in our country and elsewhere for generations to come.

On a personal note (K.K.), it was a very special privilege in my life to work with him closely. It is appropriate to recount a few anecdotal instances which in a way brought out his extraordinary personality, a man in a hurry. I vividly recall the occasion of meeting him in early 1971 at Ahmedabad airport when I had already submitted my Ph D thesis and was awaiting my final results. I had gone to see off my wife Lakshmi and son Rajesh to Bombay and Rao was also at the airport taking the same flight. Vikram Sarabhai at that time had already proposed that I join the satellite programme to be headed by Rao and the process of moving me to ISRO from PRL had been initiated. The moment we met at the airport, Rao's first question was when I was planning to join the satellite activities of ISRO? I could see his excitement when he started the conversation with his vision for initiating several space astronomy experiments in which I should play a role. He recounted the newly emerging area of astronomy, X-ray astronomy and the future potential of infrared and UV astronomies. He further went on to elucidate how he would like to set up centres of excellence in newly emerging areas of high-energy astronomy, the need to develop a variety of instrumentation for balloons, rockets and satellites as well as the realistic possibilities of working with American and Japanese institutions in progressing these activities in India. His unbounded enthusiasm and extraordinary confidence were evident all through his account delivered virtually in a monologue lasting nearly an hour. He said that he expected me to play a central role in translating this vision. This incident left a deep impression in my mind about his breadth and depth of his interest not only in technologies but also in the area of space science. In retrospect, I see the outcome of these earlier ideas in India's vibrant space-based astronomy and science activities such as AstroSat and the forthcoming *Aditya*, *Chandrayaan-2*, etc. To me, this incident had an important implication that if I had to build a future in this country, not withstanding how well I will fare, it is better to tag on to somebody who has not only the vision but also ambition, self-confidence and above all constant expression of restlessness to achieve.

In another instance which relates to the time when Sarabhai had just passed

Rao explaining a point to the former Prime Minister Morarji Desai as Dhawan looks on.

away, the possibility of India building and orbiting a reasonably heavy satellite with the help of the then Soviet Union was being seriously considered the details being available in the main text of this narration. The political decision was given at the level of Madam Indira Gandhi and President Leonid Brezhnev to go ahead with such collaboration. To further this, the details of the framework for this decision were worked at the level of M. G. K. Menon who had temporarily assumed charge of ISRO after the unforeseen passing away of Vikram Sarabhai and his Soviet counterpart academician Boris Petrov of the Inter-Cosmos Council. When the details of the same were conveyed by Menon to Indira Gandhi, she wanted an estimate of the financial implications within a day, so that the necessary decisions could be given. Menon in turn entrusted this responsibility to Rao who was in-charge of satellite activities and requested him to provide an estimate of the budgetary requirements to be passed on to Indira Gandhi. Taking into account the urgency of this deadline, Rao organized an emergency meeting of all the senior satellite divisional heads and requested them to prepare their portion of the budget estimates, giving them some guideline about the nature of the mission. When the final numbers were submitted by the functionaries, it added up to about Rs 60 lakhs. Rao showed me this estimate and immediately gave his reaction as to how infeasible it is to build a satellite with this budget. He said the issues of space qualified components, costing for infrastructure and testing, expenses towards travel and interaction with Soviet side and many such elements need better estimates. He said considering that there is not much time available to submit the final figures, we could convey to Prime Minister a preliminary estimate of Rs 3 crores (five times the number provided by the engineers), based partially on his experience in US and subsequently in India as well as partly from his own intuition of the scope and corresponding budgetary demands for the activities. What is striking about this exercise is the fact that when we completed this project 36 months after its initiation the final expenditure that we incurred was very close to '3 crores'. This shows his extraordinary acumen about the many facets of the programme, not the least his ability to assess the scope of activities and their budgetary implications. All through the years of my association with him these unique capabilities of making judgments on several matters of a complex programme he always excelled in. At all times, I felt a great excitement and freshness in working with him and never a moment of boredom. I am sure this was so with all my other colleagues. He also took special interest in the career of youngsters who showed promise for future growth I was a special beneficiary of this attitude in him. In a sense, many aspects of my own personal and professional life were shaped in my subsequent career not only in ISRO but also elsewhere thanks to my association with him.

Through this obituary both K.K. and G.J. pay humble tribute to this great personality who strode the space firmament like a colossus for nearly three decades and brought immense prestige not only to the space programme but also to our country making India's voice heard among all the major space-faring nations.

U. R. Rao is survived by his wife (Yashoda), one son (Madan) and a daughter (Mala).

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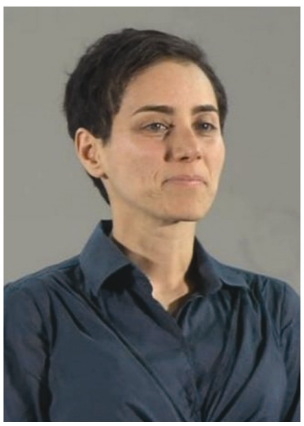
Maryam Mirzakhani (1977–2017)

Stanford mathematics Professor Maryam Mirzakhani, the first and to-date only woman mathematician to win the Fields Medal since its inception in 1936, died in USA on Friday, 14 July 2017, at the age of 40, after a four-year battle with metastatic breast cancer. Prominent mathematicians world-wide reacted to her death as follows: Peter Clive Sarnak, a mathematician at Princeton University and the Institute for Advanced Study said 'her death is a big loss and shock to the mathematical community worldwide. She was in the midst of doing fantastic work. Not only did she solve many problems; in solving problems, she developed tools that are now the bread and butter of people working in the field.' The Stanford University president, Marc Tessier-Lavigne, said 'Mirzakhani's influence would live on in the "thousands of women she inspired" to pursue maths and science.' A memorial service was held in her native Tehran, Iran. Iran's President Hassan Rouhani, who had congratulated her in 2014, released a statement expressing his great grief and sorrow: 'The unparalleled excellence of the creative scientist and humble person that echoed Iran's name in scientific circles around the world,' he further wrote, 'she was a turning point in introducing Iranian women and youth on their way to conquer the summits of pride and various international stages.'



Source: Wikimedia Commons, https://en.wikipedia.org/wiki/Maryam_Mirzakhani#/media/File:Maryam_Mirzakhani_2014.jpg

The Fields Medal is the most prestigious award in mathematics, often described as the mathematician's Nobel Prize. Mirzakhani received it in 2014 during the International Congress of Mathematicians held in Seoul, Korea at the age of 37 for 'her outstanding contributions to the dynamics and geometry of Riemann surfaces and their moduli spaces' (http://www.icm2014.org/). She is the first Iranian and first Muslim to receive the Fields Medal. Her co-recipients are also special in their own way. Artur Avila is the first South American and Manjul Bhargava is the first person of Indian origin to win the Fields Medal[1,2].