In Memoriam: Govind Swarup (1929–2020)

Prof. Govind Swarup, widely regarded as the father of radio astronomy in India, passed away on the evening of 7 September 2020. With his demise, the world has lost iconic scientist in the field of astronomy and astrophysics, India has lost a pioneer who built up a major field from scratch, and many of us have lost a friend and father figure.

Swarup was born on 23 March 1929 at Thakurdwara, Uttar Pradesh. His early college and university education was mostly in Allahabad, starting with the Ewing Christian College for an intermediate degree followed by Allahabad University for a B.Sc. in 1948 and an M.Sc. degree in 1950. Swarup often recounted being greatly inspired by teachers like K. S. Krishnan who not only taught him basic physics courses like electricity and magnetism, but also nourished and strengthened his love for science.

After completing his M.Sc., Swarup joined the National Physics Laboratory (NPL), New Delhi where again he had the good fortune to work under Krishnan, who had by then taken up the Directorship of NPL. One of the first projects that Swarup was given was in the area of magnetic resonance – to build the set-up for a spin resonance experiment. He recalled completing this task from scratch, in a short period of 18 months, which was an impressive achievement. Next, Krishnan got Swarup interested in the nascent field of radio astronomy, as a result of which the latter found himself in Australia (in 1953) – at the Radio Physics Division of CSIRO, Sydney – under a Colombo Plan Fellowship.

In Australia, Swarup worked with the group of J. L. Pawsey, initially taking up a diverse range of projects (under renowned radio astronomers like W. N. Christiansen, J. P. Wild, B. Y. Mills and J. G. Bolton), such as making 2D maps of the sun, and building receivers and electronics for radio telescopes. This provided him excellent training in various aspects of radio astronomy. In the process, he also did some interesting scientific work, including measurement of the predicted limb brightening of the sun at low radio frequencies.

Shortly after returning to India from Australia in 1956, Swarup left to work in the United States, and by early 1957 he had joined R. N. Bracewell at Stanford University for a Ph.D., working primarily in solar astronomy, but also on techniques and instrumentation for radio astronomy. After completing his Ph.D. in 1961, Swarup took up the position of Assistant Professor at Stanford.

In those early years, Swarup made many important contributions to the field of solar radio astronomy. The discovery of type U solar radio bursts, studies of the quiet sun at centimetre and decimetre wavelengths, and the gyro-radiation model for explaining the slowly-varying component of solar radio emission, are some of his notable achievements. He also continued to work on instrumentation, and during this period developed (along with K. Yang) an important and useful technique for phase calibration of antennas, which has since been used extensively in multi-element synthesis radio telescopes.

Even as his career abroad flourished, Swarup remained keen to return to India. Along with some other young Indian astronomers of his generation, he developed and submitted a proposal to several Indian research organizations for setting up a radio astronomy group in India. In 1963, upon invitation from Dr H. J. Bhabha, Founding Director of the Tata Institute of Fundamental Research (TIFR), Mumbai, Swarup returned to India as a faculty member at TIFR, and started building a radio astronomy group there. He began with a relatively modest project: the Kalyan radio telescope – an array of 32 dishes (donated by Pawsey's group in Australia) that he set up for carrying out solar studies.

This soon led to bigger things when Swarup came up with the idea of utilizing lunar occultations of radio sources to study their structure, and use them as a tool to study evolution of the size of extragalactic radio sources with cosmic epoch. The instrument he conceived to achieve this (the Ooty Radio Telescope – ORT) was based on a radical idea to build a 530 m long cylindrical antenna on a north–south hill with slope equal to the latitude of the place. Building on a slope was mechanically challenging, but it ensured that rotating the antenna in one direction only was sufficient to track sources from rise to set. The steering of the telescope beam in the north–south direction would be done using appropriate electronics. The ORT, built during 1965–70, was a truly remarkable achievement for its time, given the level of technology and expertise that was available in those days in India. It is to the credit of Swarup that he was able to attract and guide several bright, enthusiastic youngsters to form a dedicated team to build an internationally competitive facility in such conditions; and it is a tribute to this team that the ORT is functional to this date, having produced several cutting-edge science results in a wide range of fields from solar wind, pulsars, the diffuse interstellar medium, extra-galactic radio sources and cosmology. Needless to say, ORT did also address the original goal for which it was built, yielding important results on the evolution of the sizes of radio sources measured via occultation, in favour of the big bang theory for the origin of the Universe.

Even as the ORT settled down to regular operations, Swarup and his team were busy planning the next step on the growth of radio astronomy in India. What they came up with was an array of smaller cylindrical telescopes surrounding the ORT, to form the Ooty Synthesis Radio Telescope (OSRT). This venture, though not as productive and long-lived as the ORT, was nevertheless an important step in getting valuable experience with interferometric arrays and the challenges involved.

The next big step came in 1984, when Swarup came up with the concept for a large radio interferometric array to be set up in India, viz. the Giant Metrewave Radio Telescope (GMRT). The original concept was for an array of large cylindrical telescopes, but it soon metamorphosed into 34 numbers of 45 m-sized, fully steerable parabolic dishes (though finally the scope had to be reduced to 30 antennas due to funding constraints), spread out over a region of almost 30 km in diameter, at a site located about 80 km from Pune. A large number of the trained staff from Ooty moved with Swarup to set up base at Pune to execute this ambitious project. Once again, it was innovative ideas from Swarup that made this project feasible in the limited budget that was available. His novel SMART (Stretched Mesh Attached to Rope Trusses) design for the GMRT antennas, highly adapted to the desired frequency range of operation and to local conditions, resulted in realizing a 45 m-sized antenna with a weight of only about 100 tonnes, allowing the construction of a world-class observatory at modest cost. The GMRT was also one of the earliest radio observatories to use optical fibres to transport signals from the antennas to the central processing facility – a bold move which proved, in hindsight, to be one of great foresight.

The size and scale of the GMRT was such that it required a much larger team than what had been built up by Swarup at Ooty. He was once again able to attract a large number of fresh, enthusiastic members to this new challenge, and a lot of the innovative and crucial aspects of the GMRT were developed by these relatively young recruits (some fresh out of college), working in close cooperation with the more experienced members. It is a lasting proof of Swarup's extraordinary managerial skills that he got this diverse team to work efficiently together to deliver a telescope of international quality. Both of us are fortunate to have been associated with the GMRT from the early days.

From the time of its completion in 2002, the GMRT has been one of the most sensitive radio observatories in the world in the frequency range 130–1450 MHz, attracting users from all over the world and producing a slew of cutting-edge science results. It has the pride of place as one of the biggest basic science projects in the country. Swarup led the project from the concept stage to realization, becoming the Project Director in 1987. Later, when the group was reconstituted as the National Centre for Radio Astrophysics (NCRA) of TIFR, he became its first Centre Director in 1993. Even after his formal retirement, Swarup continued to keenly follow the developments at GMRT. Most recently, in March 2019, when NCRA completed a major upgrade of the GMRT (that keeps it on the forefront of global facilities), it was a privilege to have Swarup inaugurate the upgraded GMRT, coinciding with celebrations of his 90th birthday.

Even as Swarup focused on building world-class radio astronomy facilities in India, he maintained a wider vision about the international scene, and proposed ideas and projects suitable to large international collaborations. As early as 1976, he proposed an interesting global project called GERT (Giant Equatorial Radio Telescope) which came close to being taken up, but eventually could not find enough traction. Later, in the 1980s, he was one of the first proponents of a large, international radio telescope to be built primarily for the search of neutral hydrogen from the very early Universe. After some initial discussions with international colleagues, Swarup and Ron Ekers (CSIRO, Australia) successfully proposed the setting up of a 'Large Telescope Working Group' at the 1993 meeting of the International Union of Radio Science (later endorsed by the International Astronomical Union in 1994) to give shape to this concept. These deliberations converged in the early 2000s to become the concept behind the Square Kilometre Array project, which is now under implementation.

In spite of his primary focus on building facilities, Swarup never lost sight of the fact that trained manpower was just as crucial as instruments for developing a successful science programme. Apart from guiding a large number of Ph.D. students himself, Swarup took keen interest in advancing education in science in general. The Radio Astronomy Centre in Ooty was originally meant to be part of a Inter-University Centre, but unfortunately this did not work out. After his retirement from the position of Centre Director of NCRA, Swarup, along with Prof. V. G. Bhide, devoted considerable energy into trying to persuade the Government of India to set up new institutions for undergraduate training in science. This proposal was eventually carried forward towards implementation by others, and metamorphosed into the Indian Institutes of Science Education and Research that are now well known all over the country.

It is a measure of his stature that over his career Swarup received a large number of awards and recognitions (over 20 major accolades), some of the most notable ones being the Bhatnagar Award of CSIR (1972), *Padma Shri* (1973), TWAS prize in physics (1988), John Howard Dellinger Gold Medal of URSI (1990), Herschel Medal of the Royal Astronomical Society (2006), Grote Reber Medal (2007), Pontifical Academy Award (2011), and the Homi Bhabha Award for lifetime achievement by the Prime Minister of India (2009). He was also elected Fellow of several academies of science, including all the three Indian academies, The World Academy of Sciences and the Royal Society of London.

Through all of these achievements and accolades in life, Swarup remained very much down to earth, with a pleasant and approachable personality – as one of his colleagues remarked, an award day was just another regular working day. His primary interest remained science and the scientific team that he had developed around him. From technical assistants to senior engineers, from the freshest project student to top experts in the field, Swarup was equally happy to talk to them all. At the memorial meeting organized for him by NCRA, what really stood out was the diverse range of people whose lives he had touched, in one way or another. The void Swarup leaves behind will not be easy for any single individual to fill, and his rich legacy, something that we can be proud of, lights the way forward for the next generation.

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