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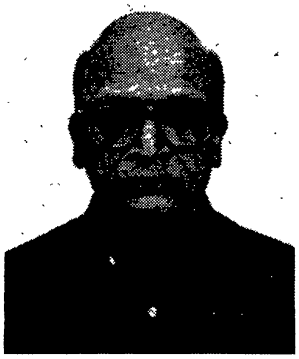

Joys and frustrations - A scientist's diary

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I have been asked to share my experiences in doing scientific research and teaching with young researchers and students aspiring to pursue a scientific research career. At the outset, let me clarify that being an experimental scientist, my experiences are mostly the reflections of developmental, observational and interpretational works. It should also be borne in mind that this is a narration of the aspirations, successes and failures in the research career of one of the several scientists in India. It is my belief that in scientific research, as in several other walks of life, not only successes but failures also generate ideas which, when implemented with renewed vigour, might lead to a brilliant success. The history of scientific research is replete with instances of this kind which have kept alive the scientific spirit of inquiry and effort.

Teaching was a thrill

Before I embarked upon my research career, I had a small stint, for one academic year, as a Lecturer in Physics in a college in Belgaum. I recall, I had a flair for teaching which, as a fresh M.Sc., I thoroughly enjoyed. Facing a beaming undergraduate class of a hundred plus students was a challenge which I accepted enthusiastically and met successfully. Of course, in the late 1950s students were more serious about their studies, a fact which made me prepare my lectures rather carefully.

The communication media, in those days, were not as informative and wide-spread as they are today. I was therefore, blissfully ignorant, in the sleepy town of Belgaum, of better avenues available to a young graduate. I was happy with my teaching assignment and deeply involved in guiding young students in carrying out their laboratory work. But somewhere in my mind there was a yearning for widening my horizon and learning more about the natural world that surrounds us.

A new vista of hope

As luck would have it, an opportunity presented itself. A casual visit to one of my erstwhile professors at the Poona University proved to be a turning point in my career. He gave me an

invaluable advice. He said "It's not enough to be on the right track; you've also to keep on moving, or else you will be overtaken by the advance of knowledge!" He was my well-wisher, and it was on his suggestion that I contacted the late Prof. K.R. Ramanathan (KRR), a renowned meteorologist, who was, then, the Director of the Physical Research Laboratory(PRL) at Ahmedabad.

I joined PRL at a time, in 1957, when it was buzzing with activities related to the International Geophysical Year. There was no prerequisite refresher course work for research scholars (RSs) aspiring to work for their doctorates. Instead, RSs were asked to work in association with senior scientists. Frankly, for many of us research topics like cosmic rays, meteorology, ionospheric physics, etc. were Greek and Latin. Totally confused, I decided to discuss the question of my Ph.D project with my supervisor (KRR). He had a towering personality and people felt intimidated to discuss things over with him. Anxious to know what I was supposed to work on, I gathered courage and approached KRR in his office. He felt my catlike entrance but without lifting his head from the book he was reading, he said "Yes, young man, what is the matter?" Balancing myself on trembling legs, I managed to speak, "Sir, I wish to discuss with you about my research project that would lead to my Ph.D thesis". "Ph.D degree? I cannot guarantee that to any one. Continue working with your senior and form your own ideas about what you propose to work on" he directed. Only then I realized that I had to read, work and think hard if I were to earn a Ph.D. During the following few years till I completed my thesis work, there were several occasions when I discussed my work with KRR. He gave a few real good suggestions. He restrained my over-confidence in my results and showed me how to explain them unambiguously. He used to say "Correct and lucid presentation is an important aspect of a thesis".

Rich dividends from a simple experiment.

Those were the days of a poor man's research often involving an inexpensive experimental set-up. In fact, I had installed a field intensity measuring equipment, comprising of a communication receiver, adapted appropriately from a U.S.Army disposal, connected to a single-wire wave antenna. The receiver was tuned to a 164 KHz signal which was being transmitted from Tashkant in the then USSR. The variations of the field intensity were continuously recorded on a strip chart recorder. This was one of the simplest experimental set-ups. Surprisingly, it paid rich dividends. These very low frequency (VLF) waves are reflected from the D-layer (about 60-80 km high) of the ionosphere. Any changes in the intensity of the solar radiation, ionizing NO (nitric oxide), result in electron density variations of this layer. The latter cause corresponding intensity changes in the reflected signal. This effect could thus be used as a sensitive index of solar activity, such as flares. Certain patterns of these VLF effects were characteristic of the class of the flares. During major geomagnetic storms, night-time intensity fluctuations were found to be more chaotic.

A good database is a gold mine

A good database is often a latent goldmine. On completion of my thesis work I switched over to Solar Radio Astronomy (SRA). My VLF experiment was then taken over by Sahadeo

Ananthakrishnan (now in Brazil). He concentrated on the nocturnal intensity behaviour. Although this was highly variable, its average levels were found to be affected by the presence of the X-ray source, Sco-X1! It was believed that the VLF intensity enhancements were due to extra ionization caused by the X-radiation (Ananthakrishnan & Ramanathan). This was a very high dividend from a meagre investment!

A few years later, during a visit to the Cavendish Laboratory, Cambridge I was lucky to see the simple vacuum-tube receiver with which Tony Hewish and his student Jocelyn-Bell discovered the pulsar. Awe-struck, I asked Hewish as to how they could make the astounding observation with that antiquated receiver! He quipped, "due to the combination of a wellhoned telescope, vigilance and a bit of luck. The last, because my IPS array was looking at the interesting portion of the sky where the pulsar CP 1919 was spinning!" Thus, a discovery is often shrouded in a good database; one has to scoop it out by improved observations and efficient analysis!

Diversion from routine

During 1969-73, I decided to go in for a change from my research work when I got a senior scientist's assignment at the Institute of Space Research in Brazil (INPE). It is a federal organization, which was then in its infancy. They had invited several experienced physicists from U.S.A., U.K., France, Japan and other countries to train Brazilian graduates for their master's degree as well as to initiate them into research projects. I had three bright students, who wanted to work on Radio Astronomy (R.A.) techniques. This was an excellent opportunity of studying the fundamentals of R.A., and what better way is there than teaching? As a project work, these students and I developed a radio telescope (R.T.)! We measured several antenna parameters precisely. They agreed well with the formula for array sensitivity given in his well-known book by the radio astronomer J.D. Kraus. We communicated these results to him for his comments. He was very happy to see the application of his formula and encouraged us to work on larger arrays. I presented this work in an international conference on "Antenna and Propagation" held at the Tohoku University, Sendai, Japan. Only an expert understands the importance of good work, small or large!

Being basically a physicist, I craved for doing some research work too. The discoveries of IPS, and , a little later, pulsar by Hewish and co-workers fascinated me greatly. But at INPE I was alone in this respect. I read a few papers available on the Cambridge work. I compared their results of scale-size of plasma density inhomogeneities, that caused IPS, with calculated variations of proton gyro-radius as a function of distance in the solar corona. The results agreed qualitatively. I communicated this small piece of work to Hewish, unknown to me then. He was happy with it, and suggested that I publish a research note. That was another example of encouragement from an expert. This incidence was to mark the beginning of my association with Tony Hewish and his colleagues which continues until this day!

Initiation in IPS

A little before the end of my three-year assignment at the Brazilian space research institute, Hewish informed me, upon my query, about a post-doctoral position available in the Department of Radio Science, Adelaide University, at Adelaide. His ex-student (Paul Dennison) who was on the staff of the department, was nearing the completion of a 3-site IPS observatory. This was an excellent opportunity to learn all about IPS. I wrote to Hewish expressing my keen desire to work with Dennison, who had by then published some good papers on basic IPS results. A few days later I received an offer from the Adelaide University. Dennison was a very bright person, who had received good grinding from Hewish. He was very friendly too. Transcending international barriers, we became good friends. It is here that I received basic lessons on IPS physics along with a sound training about the technique. Occasionally we used to consult Dr. Basil Briggs, a well-known physicist who had good knowledge of various types of physical data and had published classic papers on statistical analysis of such data. I was highly impressed and benefitted by his deep insight into the behavioural patterns of atmospheric as well as interplanetary data.

In addition to the regular weekly seminars of the Radio Science department there used to be special weekly discussions on "literature survey". Anyone could briefly present new results, either his own or those appeared recently in a journal, which were discussed, there, by all present. According to Briggs, the practice of "literature survey" keeps one abreast of current state of one's field of interest. On my return to PRL, I initiated such discussions in our 'area', which lasted a little over a year. Sustaining a long-lived interest in an academic activity has been a traditional problem.

Development of Solar Radio Astronomy at PRL

Charged with new ideas and well equipped to carry them out I returned to PRL in early 70s. I joined Prof. R.V. Bhonsle who had proposed to build a group for studying Solar Radio emissions at meter, decameter and centimeter wavelengths. The main aim of this plan was to study these radio emissions by measuring their various characteristics. In particular, these were intensity variations of solar burst emissions simultaneously as functions of the operating frequency and time; in other words, dynamic-spectra and polarization by measuring the Stokes parameters (I,Q,U,V). The slowly varying or the S-component of the solar radio emission, which maximized at a wavelength of 10 cm, is a good index of solar activity. Thus, regular measurements of intensity and polarization of meter and decameter wavelength solar burst radiation together with that of daily well-calibrated cm-wavelength flux density were thought to be a good overall study of solar radio emissions. It was also believed that these studies would form an important input to the broader studies of solar-terrestrial relations which PRL was committed to pursue.

Out of both the necessity as well as the limitations of funds, we had to design, develop and fabricate, in-house, most of the instruments that would require to make the measurements discussed above. With our small but dedicated group of electronic engineers and technicians we assembled a solar radio spectrometer (with German made fast scanning receivers, 70-240 MHz),

developed a 4-channel radio polarimeter and a 5' parabolic dish microwave flux radiometer. These instruments were operated over nearly a solar cycle, during which period dynamic spectra of a variety of solar radio bursts were recorded. These were complemented by polarization measurements. Several papers resulting from this work have been published in reputed journals.

Most of the developmental work of this project was done under the supervision of Prof. Bhonsle as he had done similar work abroad. He had good insight and practical knowledge of electronic instrumentation. Thanks to him, I was immensely benefitted in this aspect. This invaluable experience stood me in good stead in my later years. The team work combined with our jovial nature (we were called Laurel & Hardy!) has been the secret of our long association of over 25 years, an uncommon feat in our institutions.

Team work - strength of experimental projects

This team spirit and the expertise built up in the R.A. group were put to a test during the total solar eclipse of 16 February, 1980. The path of totality was to pass over the Japal-Rangapur Observatory of the Osmania University near Hyderabad. We had planned multi-frequency observations of the radio sun during the immersion and emersion of the solar disc behind the lunar disc. Four radiometers operating at frequencies of 2.8 and 10 GHz belonging to PRL and Osmania University respectively and at 19 and 22 GHz to the Space Applications Centre, Ahmedabad were installed at the Rangapur Observatory under our supervision. The duration of totality was about 3 minutes and the beams of the four antennas were centered on the sun, so that the same active regions of the radio sun were scanned at these microwaves. To gain confidence in this exercise, solar scans were regularly made for about a week prior to the eclipse and nothing was left to the chance. No wonder, the eclipse observations went on smoothly, and we collected good quality data only at three frequencies, since the 10 GHz radiometer developed automatic tracking problems. I had the additional responsibility of digitizing, processing and analysing the large amount of data. The potentially high resolution data were compared with one another, and identical active regions were identified. Variations in their fluxes and sizes were studied. This once-in-a-life event was a thrilling and satisfying experience, a result of a well-organized campaign and dedicated efforts.

Proposal writing warrants single-minded dedication

My plans of initiating studies of interplanetary medium (IPM) received strong support from Prof. Ramanathan and Prof. Bhonsle. In a way, this was an extension of our decade long solar studies and the method of IPS that we proposed to employ was based on radio astronomy techniques. The first and the foremost problem was to come out with a proposal that would enhance our understanding of the IPM in general and the solar wind in particular. The scientific objectives thus defined we had to choose the observational method, develope, fabricate in-house and outside and test other equipments; data processing methods, work schedule, man-power requirements. And, last but not the least, funds had to be assessed. We had proposed to set up a three spaced-telescope system for the measurement of solar wind speeds using the IPS method. It was my first experience of working on a proposal of such a large scale. I had to work single-

handedly on it for several months before the first draft was ready. I found it an invaluable exercise for I had to study most of the published work on IPS and related topics to enrich my understanding about the IPM.

I felt I was on the top of the world when we learnt that our project was approved by the Department of Science & Technology, to whom we had submitted our proposal for funding. I had just returned from 1977 COSPAR meeting held at Tel Aviv and, fortunately for us, Prof. Kakinuma accompanied me to PRL for a short visit. He had already set up a three-site solar wind observatory in Japan. A man of few words (even in the Japanese language), he was well known for his expertise in radio astronomy techniques and methods of spectrum analysis. Prior to the beginning of our project work we were immensely benefitted by his practical experience in the IPS field. A good rapport was established between Kakinuma and our R.A. group and it became closer and more beneficial over the next several years.

A challenging task

The morale of the group was very high and all its members were excited as they had a new challenge to meet. As an experimenter I knew that the technical personnel have a lot to contribute to such a project and that they like to take up challenging tasks. Planning, organization and implementation were the most crucial prerequisites of such a large-scale project and we were educating ourselves as we were going ahead. I shall skip over the details of the numerous hurdles and delays caused in acquiring a large variety of equipments and consumables (local and foreign) which went into the first Radio Telescope that we developed for IPS observations. Such difficulties are, to a certain extent, unavoidable and are a fact of life. All the same, they did at times throw cold water on our enthusiasm! Recalling his experience, a well known astronomer wrote to me "it is always later than planned". I sustained my enthusiasm.

The first IPS telescope was commissioned much before the stipulated period of three years. This achievement was well appreciated by Dr. A. Ramachandran, the then DST Secretary, who visited the Thaltej site. The same evening, during his talk at the Community Science Center at Ahmedabad, Dr. Ramachandran was reported to have paid high tributes to the dedicated work done by our group. Our happiness knew no bounds!

Beauty lies in the eyes of the beholder

A couple of months after the above incidence, Prof. Hewish was to visit India at the invitation of the GOI in connection with the then called the Giant Equatorial Radio Telescope. In an attempt to grab the golden opportunity, I sent a telex message to Hewish requesting him to include in his itinerary a day's visit to PRL to see our telescope which had begun recording IPS. To my pleasant surprise, he accepted my informal invitation! It was a public holiday in April 1979. We escorted him to the PRL guest house for a little rest and a cold drink. I could see that he was very impatient to see the telescope. As soon as we stepped out of our car at the Thaltej field station, Hewish had a glimpse of the IPS array. He exclaimed, "Ah! I feel at home here!" Surprised at this excitement, the late Prof. Ramanathan who had accompanied us, asked

Hewish what made him feel so jubilant even when the mercury had touched 43° C! Hewish explained that it was the sight of the nicely erected antenna array that attracted his attention. Beauty lies in the eyes of the beholder (who knows what's beautiful about the thing). During the next few hours he thoroughly examined the entire radio telescope including the quality of IPS recordings. He expressed his satisfaction at our first IPS telescope and made some valuable suggestions. This was the beginning of our association with the Cambridge group, which was to last for more than a decade.

Learning transcends age barriers

The visit of a bright young scientist from Cambridge is a memorable one, Dr. Peter Duffett-Smith, 29, was invited by PRL as a visiting Professor for a month. He was to give a series of lectures on IPS theory and observations and a few seminars on results obtained by the Cambridge group. These were very well received by PRL scientists, and were particularly useful to the IPS group. In addition, having an excellent knowledge of the experimental set-up at Cambridge, he spent considerable time discussing details of our IPS system with our engineers and technicians. The brilliant performance of this visitor was, however, not whole-heartedly admired by all. A senior scientist was feeling rather uneasy about it. Over a cup of tea he remarked "We should not invite such young scientists, it is embarrassing to listen to them!" Scientists have to be open-minded and appreciative, no matter who delivers good science, young or old. We should take a leaf out of their book.

We had to sustain the enthusiasm of the group as two more telescopes were to be installed at Rajkot and Surat. The first is a rocky terrain while the second is a soft black cotton-soil, requiring different techniques for erecting large antenna arrays. It is gratifying that the Telecom Department, Gujarat Circle, to whom the responsibility of installing all the three arrays was entrusted, completed the job with professional skill. With some delay, which was unavoidable, these two telescopes also went in operation. Ideally, work of the three telescopes should have been started simultaneously to minimize the delay. However, we found this unfeasible. Anyway, we were very happy when we started getting good estimates of the daily solar wind velocities when the IPS data of the three telescopes were cross-correlated.

Bonus on good investment

There are umpteen number of occasions in the history of science when naturally occurring phenomena have been observed by instruments which were not meant for those purposes. In the early 80s I was visiting the IPS group of the Nagoya University, Japan. Prof. Kakinuma was showing me round their computer center. He introduced me to a young scientist who was working on a programme which identified scintillating radio sources that would possibly 'shine' through the ion-tail of the Halley's comet. I saw that there was one source (3C 459) that was predicted as a candidate. We had been observing IPS of this source for a few years by then. I was very excited at this information and requested the predicted occultation details from Kakinuma.

Back home we wanted to see, if the Halley's comet developed near the perihelion a sufficiently dense ion-tail with micro-scale density fluctuations, whether or not enhanced scintillations of the source would be caused when it shines through the Halley's tail. Our success raised, as often happens, a controversy regarding the observed enhanced scintillations. This is a part of the scientific method; strong convictions about a well-observed event, followed by another set of observations of a similar event by someone else to verify the first observations. A critical examination of these contradicting observations showed that the solar elongation should be large enough to minimise the scintillations caused by the solar plasma during the passage of cometary tail across the source. This conclusion was substantiated by similar observations on several occasions involving comets Kohoutek, Austin and Wilson, the last observed in Australia.

Frustration - a fact of life

We also had our share of frustration. The IPS data at Surat started getting highly contaminated due to local electrical disturbances as well as due to FM transmissions. In addition, due to lapse of security in the university campus, expensive coaxial cables used for the antenna array were stolen repeatedly. On every occasion this was brought to the notice of the university authorities, but in vain! Disappointed, we had to close down the IPS site. Maintaining field stations at remote places is a great responsibility which should preferably be undertaken by the parent institution.

I recall almost a similar experience which the Japanese scientists had undergone. They were operating a three-site IPS observatory at a VHF, at which there was a lot of interference from the wide-spread communication network in the country. They had therefore to switch over to a protected frequency in the UHF band.

A silver lining

We did have a consistent and good quality IPS database, made with the more sensitive telescope at Thaltej (Ahmedabad), covering nearly a solar cycle. Thanks to the Ooty scientists, we adopted their software method of estimating solar wind velocities using a single-site IPS data. From the resulting velocity values we prepared synoptic velocity-maps which identified regions of low and high-speed solar wind near the solar surface with good accuracy. These V-maps clearly brought out the influence of solar cycle on the velocity structure of the solar wind. Also an inverse relation between plasma density and solar wind speed was inferred.

IPS imagery

In the early 80s, Hewish and co-workers at Cambridge pioneered a method for producing a scintillation imagery of the interplanetary medium (IPM). Called "g-maps", such daily maps are based on IPS observations of hundreds of radio sources and mapping the observed fractions of their scintillating fluxes as a function of solar elongation. The daily fluctuations of the fractional scintillating flux of each source are compared with its long-term average value. The ratio of these two quantities is a measure of the enhanced scintillation and is called the

enhancement factor, 'g'. Scintillation enhancements or depletions in the IPM caused by interplanetary propagating disturbances are expressed in terms of 'g' values, where g=1 corresponds to the average density of the medium, and is calibrated in terms of the actual density using spacecraft data. Thus, the 'g-maps' in effect can be reduced to density-maps of the IPM. Briefly, using such maps it was shown, on the basis of strong evidence, that the interplanetary propagating disturbances originate in mid-latitude coronal holes, and not in near-surface activities such as solar flares according to the traditional belief. Naturally, these Cambridge results raised a lot of controversy. More IPS observations were planned to independently cross-check these observations. Under a collaborative Indo-US project with the NOAA scientists, it was decided to enhance the sensitivity of the Thaltej telescope, by appropriately enlarging its antenna aperture and using a multi-channel receiver system, such that a large number of scintillating sources were observed daily. This was a tremendous task, both in terms of the technical development and the fabrication.

The unfinished job

We finalised the design of the new receiver system after discussing with the experts from Cambridge and NOAA. The antenna array was enlarged with the help of the Telecom Department, Gujarat Circle. The major apprehension we had was the inordinate delays that would occur in procuring some electronic components, large amounts of coaxial cables etc. and huge quantities of sheet-metal jobs. A crucial decision was to be made for the fabrication of the last non-trivial item. Considering the work-load Dr. Bhonsle (P.I.) and I (Co-PI) decided to offload the job to the local manufacturers. Unfortunately, this proved to be a wrong decision. We had no control over these people nor did we have any alternative! The resulting inordinate delays from all these jobs were very frustrating!

The large array was ready and one by one the new receivers were being added. Around this time, Dr. Bhonsle superannuated, although he continued as an Hon. Professor at PRL for a year. I did, thereafter, feel rather lonely, but we continued with our single-minded dedication to our responsibilities.

However, our stars were in the descendant! Signals from the recently commissioned FM transmissions started interfering with the IPS observations, inspite of the fact that our operating frequency band (103 ± 1.5 MHz) was supposed to be protected within a circle of 200 km radius! We had no option but to narrow down the receiver bandwidth at the cost of the sensitivity. This we did, but the interference was still too strong! These last-minute modifications in the complex system consumed a lot of time, but in vain! Shortly thereafter I attained my superannuation and called it a day.

To sum up, in the fulfilment of some of my research work I have experienced a deep sense of satisfaction. This is the reward of a thorough job of research accomplished with my colleagues. The task which remained incomplete caused frustration. I give solace to myself in the words of the poet Robert Herrick:

"Attempt the hard, and never stand to doubt; Nothing's so hard, but search will find it out".