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October 4, 2020

To
Dr. Yashwant Gupta
Director, National Centre for Radio Astrophysics
Pune, India

Dear Yashwant:

At your request for a contribution to the forthcoming memorial meeting (October 7, 2020) to remember and celebrate Govind Swarup's contribution to radio astronomy I am contributing this somewhat long reminiscence. This letter documents my first encounter with Govind, the professional support that I received from him and concludes with my views of his pioneering role in Indian and global radio astronomy.

In 1976, V. Radhakrishnan, then Director of Raman Research Institute (RRI) and Swarup (then Director of the Ooty Radio Telescope, ORT) decided to hold a summer school centered around Astronomy & Astrophysics [1] on RRI campus, Bengaluru. It is important to remember that in the '70s astronomy was not a part of the Indian school nor the college syllabi. The summer school was aimed at MSc students presumably to entice them to the burgeoning astronomy PhD programs at RRI, the Tata Institute for Fundamental Research (TIFR) and the Indian Institute of Astrophysics (IIA).

In 1976, I was in my third year of the "Integrated 5-year" MS "Engineering/Applied Physics" program at the Indian Institute of Technology, Delhi (IITD). The department was unusually strong in optics (the celebrated A. Ghatak) and quantum optics (the famed C.L. Mehta). I started a small project with Dr. S. Chopra who had recently joined the department as an Assistant Professor. He had obtained his PhD at University of Rochester working with the famous experimental and theoretical physicist, L. Mandel, one of the founders of quantum optics. Dr. Chopra was keen to start a program of designing and building digital processors to measure various statistics of photon arrival times.

My knowledge of astronomy was limited to what I had read in *Scientific American* in the libraries of Dharwad University and IITD. I certainly had no knowledge of astronomical research that was being undertaken in India. Nonetheless, when I saw the posting of the RRI summer school on the bulletin board I was intrigued and immediately applied. The application was rejected because I was in my third year which was the equivalent of BSc III.

However, I had my own scholarship – a National Science Talent scholarship from National Council of Educational Research and Training (NCERT) – which generously provided stipend through the academic year, admission to summer schools (with funding) and purchase of textbooks. Summer schools for NST scholars were held at various laboratories around the country to expose the scholars to various areas of their chosen majors. One of my professors informed me that Swarup was visiting IITD and suggested that I persuade him to admit me to the school. I duly met him at the Guest House of IITD and made my case.

He was supportive and in due course I was admitted.[1] Govind was fond of reminding me of this first encounter at IITD. In fact, he gleefully recounted this meeting during my last (and final) meeting I had with him (April 2019, Pune). Govind told me that he thought anyone who is enthusiastic and determined should be a given chance and that is why he permitted me to attend the summer school. In some ways – enthusiasm, energy and determination – provide the most compact description of Govind.

The 1976 summer school proved to be a hit. We had lectures not only from Swarup and Radhakrishnan but many young people, some who had obtained their PhD in India (e.g. R. Nityananda) and some who had returned from abroad (e.g. G. Srinivasan, C. Shukre, D. Mallik). As a part of the summer school we visited the Kavalur Observatory[2]. There was a sense that Indian astronomy – with ORT, Kavalur, Aryabhata X-ray satellite and theory groups with global standing at TIFR and RRI – was about to takeoff. The summer school met its objective with many participants enrolling into an astronomy PhD program the next year (C. Jog, A. Pati, G. Saikya, R. Nandkumar, S. Sukumar and others; see photograph at the end of the letter).

Govind took interest in me and issued a carte blanche invitation to visit ORT. I spent the winter vacation at ORT. With support from ORT technical staff I finished my first experimental project, a variable lag photon-counting digital "clipped" (1-bit) auto-correlator. The successful completion of this project led me to design and build a 64-channel photon clipped correlator for my undergraduate thesis [2]. The winter trip convinced me that my future was in radio astronomy and not in physics. Having concluded thus I returned to Ooty again in 1977.

The main programs at ORT, commissioned in 1971, were (1) using the method of interplanetary scintillations (IPS) to crudely determine angular sizes of radio sources, (2) lunar occultation for even finer angular studies and determination of position and (3) search for the deuterium hyperfine line. In Ooty, I undertook a ground-up study of interferometry, both amplitude and intensity, and IPS theory. During a lunar occultation, the chart recorder pen provided a thrilling and dramatic demonstration of Fresnel integrals. During my stay, Govind tried to interest me in pursuing IPS research. However, as he recounted to me during the 2019 April meeting, I apparently declined, saying that the program was (1) already populated by many astronomers and (2) it had a limited future scope! It is to Govind's credit that such a frank reply did not make him lose in interest in me.

During my stay at Ooty I still recall some of the wild ideas that I would propose to Govind, almost every day, to "improve" ORT (e.g., mercury filled tubes with valves to change the center frequency of reception). Govind listened to these ideas and worked with me through the details (and in almost all cases the scheme would turn out to have a fatal flaw). I was a guest for dinner on more than one occasion at his Ooty house and that is when I first met Bina. Upon return I decided that I wanted to pursue a thesis ground in radio astronomy but with an eye towards optical intensity interferometry.

At the summer school I also befriended Rajaram Nityananda who had recently joined RRI after finishing his PhD at the National Aeronautical Laboratory. Rajaram had a deep understanding of waves and optics. I spent subsequent the summer vacation at RRI[3]. I had planned on enrolling for a PhD program at RRI with Rajaram as my advisor. However, at some point, Rajaram thought that my desire for an experimental

[1] A domino effect was that my two class mates, Milind Purohit (now Dean, Okinawa Institute of Science & Technology and Sudhakar Prasad, University of New Mexico & University of Minnesota) also sought and were admitted to the summer school!

[2] Now renamed to Vainu Bappu Observatory. It is located about 170 km South and East of Bengaluru.

[3] Staying at Rajaram's RRI apartment – *gurukul* style -- and going through Cambridge physics problem set.

thesis in Radio Astronomy was best pursued by going to the US. I applied to Berkeley, Caltech and MIT. Caltech rejected me and MIT admitted me with no financial aid. By August of 1978 I found myself with a graduate research assistantship from the Radio Astronomy Laboratory (RAL; C. Heiles, J. Welch, D. Backer), University of California, Berkeley (UCB). Thanks to my stay at Ooty and interactions with Rajaram I had developed a deep understanding of interferometry. This investment paid off with the invention and implementation of an innovative mode for the newly commissioned Very Large Array (1981) and an air-linked interferometer at Arecibo for HI absorption spectroscopy (1982). I graduated from UCB with a PhD in 1983. After a brief post-doctoral period, I joined Caltech in 1985 where I have remained ever since.

In subsequent years Govind and I kept in touch with each other but we had little professional interaction mainly because my interests switched to other areas of astronomy (optical-, X-ray- and γ-ray-astronomy). Govind was keen to see me return to India and made a major effort every time the Directorship of IIA opened up. I was too deep rooted in the US to return to India. Furthermore, my heart was not in optical astronomy and so returning to India to push optical astronomy was simply not in the cards. Incidentally, I became Director of the Caltech Optical Observatories[4] out of a sense of duty. In 2018, after over twelve years of service, I stepped down and promptly returned to my roots: radio astronomy and the diffuse interstellar medium. Every now and then my wife and I wonder whether we made the right decision to continue to stay in the US.

The words that come to me when I think of Govind are: energy, enthusiasm, hard work, persistence but most importantly execution. Govind was a true pioneer of radio astronomy. He built two world-class facilities in a relatively poor developing country. He showed that with sufficient grit and determination world-class experimental research can be undertaken in India. However, to achieve this you have to be dedicated. As a student of the ultimate clinical analysis of life – the *Bhagvad Gita* -- on this day I would like to celebrate Govind's spectacular life by saluting the *numero uno karma yogi* of our era.

I would like to take this occasion to suggest re-purposing[5] TIFR's investment at Ooty: ORT and the Cosmic Ray Laboratory (CRL). The two facilities taken together can undertake research in lightning [3,4] and space physics (mapping the solar wind via IPS [5] and sensing interplanetary magnetic fields via muon intensities). In fact, given that our eco-system is increasingly fragile (floods, fires, pandemics, drought) it would be prudent to monitor space weather and build early-warning systems to safe-guard our satellites and electrical grid. The traditional interests of both cosmic ray research and radio astronomy can continue with the merged facility: cosmic rays at the knee can be studied by combining radio and particle physics techniques [6] and ORT with its upgraded wide field-of-view [7] can commensally monitor and explore the meter-wave sky for transients on timescales starting at milliseconds [8]. I am sure Govind would have pleased with this ambitious suggestion.

Sincerely

S. R. Kulkarni

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Principal Investigator, Zwicky Transient Facility
George Ellery Hale Professor of Astronomy & Planetary Sciences

[4] Consisting of the Palomar Observatory, California and the W. M. Keck Observatory, Hawaii.
[5] This proposal comes directly from discussions I had with my long-standing friend Dr. Sunil Gupta (Director of CRL, emeritus) during my visit to TIFR as a part of my JRD Tata Chair Professorship.

Attachments:

1. Bibliography
2. Group photo of the 1976 summer school

BIBLIOGRAPHY

[1] B. M. Meera & M. Manjunath, *H-Index of Astrophysicists at Raman Research Institute: Performance of Different Calculators* (2012). https://ui.adsabs.harvard.edu/abs/2012wgl..conf...46M

[2] H. Bohidar, S. R. Kulkarni, S. Prasad & S. Chopra, *Design and fabrication of a digital correlator* (1980). https://ui.adsabs.harvard.edu/abs/1980JPhE...13..614B/abstract

[3] B. Hariharan et al., *Measurement of the Electrical Properties of a Thundercloud Through Muon Imaging by the GRAPES-3 Experiment* (2019) https://journals.aps.org/prl/abstract/10.1103/PhysRevLett.122.105101

[4] T. Enoto et al., *Photonuclear reactions triggered by lightning discharge* (2017), https://www.nature.com/articles/nature24630

[5] P. K. Manoharan, C. R. Subrahmanya & J. N. Chengalur, *Space Weather and Solar Wind Studies with OWFA*, (2017), https://ui.adsabs.harvard.edu/abs/2017JApA...38...16M/abstract

[6] S. Thoudam et al., *Measurement of the cosmic-ray energy spectrum above 1016 eV with the LOFAR Radboud Air Shower Array* (2016), https://ui.adsabs.harvard.edu/abs/2016APh....73...34T/abstract

[7] C. R. Subrahmanya, P. K. Manoharan & J. N. Chengalur, *The Ooty wide-field array* (2017), https://ui.adsabs.harvard.edu/abs/2017JApA...38...10S/abstract

[8] S. Bhattacharya et al., *FRB Event Rate Predictions for the Ooty Wide Field Array* (2017), https://ui.adsabs.harvard.edu/abs/2017JApA...38...17B/abstract

SUMMER SCHOOL

IN

ASTRONOMY, ASTROPHYSICS AND SPACE PHYSICS

HELD AT

RAMAN RESEARCH INSTITUTE, BANGALORE-6.

MAY 16 TO JUNE 11, 1976.

SITTING : (L to R) Sushama Mallik, Savita Mohan, Y. K. Latha, Jayashree Tasker, M. Raj Lakshmi, Chanda Jog, Anita Mirchandani, B. R. Pushpalatha, Sarmistha Sahu.

Second Row : (L to R) D. K. Ravindra, K. T. Balakrishnan, Dipankar Mallik, Rajendra Bhandari, Sudhakar Prasad, T. R. Ram Dass, K. G. Ravi Kumar, J. S. Cornelins, Srinivas Kulkarni, Madan Mohan Tripathy, K. R. Anantharamaiah, Harish Chandra Bhatt, D. J. Saikai, V. R. Venugopal, J. C. Bhattacharya, P. V. Ramana Murthy.

Third Row : (L to R) Rahul Pandit, R. S. Arora, Ashok Singal, T. Chandrasekhar, D. Mukundan, Rajaram Nityananda, Prasun Deb, Indrajit Banerjee, Milind Purohit, Ashok Pati, K. L. Venkat Krishnan, S. Sukumar, N.V.G. Sarma.

Last Row : (L to R) K. V. Balachadra, P. Ram Babu, A. Ratnakar, G. Srinivasan, S. B. Nadkarni, A. Bhattacharya, S. S. Madan, M. Sebastian, A. T. Hameed, C. Shukre, V. Radhakrishnan, M. N. Ramanuja, G.V. Srinivasa.