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Special issue in honour of Prof D V G L N Rao

Prof D V G L N Rao

Guest Editors : D N Rao & Chandra S Yelleswarapu

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Asian Journal of Physics

Edited by

D N Rao & Chandra S Yelleswarapu

Asian Journal of Physics

Volume 30 No 12 December, 2021

A Special Issue Dedicated
to
Prof D Rao

Guest Editors: **D N Rao**
Chandra S Yelleswarapu

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Guest Editorial

With deep respect and admiration, we cordially welcome you to this special edition of the Asian Journal of Physics, dedicated to commemorating the remarkable career of Prof DVGLN Rao, Fellow of the American Physical Society and Distinguished Professor of Physics. As an exemplary educator and research Advisor, he has nurtured talents, inspired independent research endeavors, and provided invaluable guidance to students at all levels, postdoctoral fellows, and visiting scholars, including the guest editors of this issue. Prof Rao's influence extends beyond the impartation of fundamental scientific principles; he illuminated pathways toward practical applications.

The broad-spectrum underscores Prof Rao's significant contributions to nonlinear optics and its applications in optical power limiting, Fourier Phase Contrast Microscopy, and Image Processing for biomedical applications. As guest editors of this edition, we are honored to curate a compilation of a diverse array of articles, from theoretical breakthroughs to tangible applications, each authored by researchers whose professional careers reflect Prof Rao's mentorship and the enduring legacy of his teachings..

Prof Reji Philip worked in the lab of Prof D Gopal Rao on two sabbatical visits from the Raman Research Institute, Bangalore, India, where he leads a nonlinear optics lab, which stands out as one of the best in the country. In the article "Nonlinear optical properties of certain colored, free-flowing, dye-based fountain pen inks", Prof Philip and co-authors investigate the nonlinear optical properties of light-absorbing inks which can be demonstrated by low power laser sources.

Prof Sri-Rajasekhar Kothapalli, who is an Associate Professor in the Biomedical Engineering Department at Penn State University, is one of Rao's many graduate students. He acknowledged in his words, "*As a masters student in Applied Physics at UMASS Boston, I published my first paper under the guidance of Prof Rao. This work involved the development of an optical holography technique for image processing of biological samples. With the encouragement that I received from Prof Rao, I published 5 papers during my master's, including 3 as a first author. My master's thesis work with Prof Rao piqued interest in biomedical optics and later completed a Ph D in Biomedical Engineering from Washington University in St Louis with Prof Lihong Wang. I take this opportunity to thank Prof Rao for trusting in my abilities and giving me the confidence to establish my scientific career*."

The article by Kothapalli *et al* on blood oxygen saturation measurement demonstrates the application of nonlinear optics in biomedical research, aligning with Prof Rao's interests in nonlinear optics and its applications to biomedical applications. By integrating the well-known optical Z-scan technique with sensitive photoacoustics, the study offers insights into non-invasive methods for assessing physiological parameters, reflecting the interdisciplinary nature. The findings reveal a direct correlation between the nonlinear absorption coefficient and blood SO2 levels. This streamlined single-wavelength approach obviates the necessity for bulky, multiwavelength lasers, potentially facilitating the portability, affordability, and widespread adoption of this technology.

Dr N Sri Ram Gopal happens to be a masters student at University of Hyderabad and DNR saw the great potential in him as a researcher and suggested him to join Prof Rao's lab at UMASS, Boston for pursuing research work. After working for couple of years under Prof Rao, Ram Gopal completed his Ph D from USA and joined as a faculty member at University of Hyderabad, India, to work in the area of nonlinear optics. Dr Ram Gopal alongwith his co-workers contributed some of his recent results through the manuscript, "Wavelength dependent cubic nanoparticles formation on copper surfaces by femtosecond laser irradiation".

The investigation into carbon nanoparticles' nonlinear optical properties highlights the potential for practical applications in laser irradiation control, a domain closely related to Prof Rao's work in optical power limiting. In the study titled "Nonlinear Optical Properties of Carbon Nanoparticles in Sol-Gel Composites

Studied by Optical and Photoacoustic Z-scan Techniques," Dr Yelleswarapu's team investigates polymer composites containing fullerene and onion-like Astralens nanoparticles, comparing them to their liquid suspensions. They assert promising prospects for these materials as limiters of laser irradiation.

For many years, Prof Rao taught two-semester graduate-level courses in laser and nonlinear optics labs in UMASS, Boston, USA. These courses not only deepened student's understanding of theoretical concepts but also furnished them with invaluable hands-on experience. Dr Niyom Lue is one of the many students for whom practical knowledge proved instrumental in guiding his doctoral research and continued academic pursuits. In honor of Prof Rao, Niyom has written a short review on off-axis quantitative phase methods and their variations for label-free biomedical microscopy applications. In fact, this special issue would have been incomplete without an article on phase microscopy, resonating with Prof Rao's pioneering work in advancing imaging technologies for biological research.

Research on Polyaniline thin films, by Prof Huyen, emphasizes the development of functional materials with tailored properties, echoing Prof Rao's focus on exploring novel materials and their applications. The study's attention to thin film fabrication techniques reflects Prof Rao's expertise in experimental methodologies and characterization techniques.

Prof Gopal Rao had done pioneering work on porphyrins, which show very high third order nonlinear susceptibility and this has led to many research publications on porphyrins and phthalocyanines. Prof Chandrasekharan, who had many years of research interaction with Prof Gopal Rao shares his optical limiting research through the article titled "Nonlinear optical transmission and optical power limiting characteristics of axial bonding type tin (iv) porphyrins with different peripheral substituents at the meso-positions".

After joining University of Hyderabad as a faculty member, Prof D Narayana Rao (DNR) used to visit Prof Gopal Rao's Lab very frequently during the summer holidays and learned many techniques on nonlinear optics, particularly with bacteriorhodopsin and porphyrins. One of these studies fetched him a patent. As a respect towards his mentor, Prof D Gopal Rao, DNR alongwith his students contributed an article titled "High spatial frequency laser induced periodic surface structures". This research has significant effect on surface structuring of the materials and effectively controlling their reflectivities, both as a function of wavelength and intensity, and/or make them either hydrophobic or hydrophilic.

Prof Sukhdev Roy had a long interaction with Prof D Gopal Rao as his initial studies were on bacteriorhodopsin. Prof Roy and his students contributed an article "Theoretical analysis of optogenetic excitation of ON and OFF retinal ganglion neurons" in honour and respect of Prof D Gopal Rao's.

Dr Guiru Gu is another former student of Prof D Gopal Rao. Her contribution along with her coworkers in this special issue is titled "Printable metallic nanoparticle-induced surface plasmonic resonance enhancement on infrared photodetector under femtosecond laser frequency comb illumination," reminiscent of Prof Rao's emphasis on practical applications and technology development.

Prof Fuchs *et al* in his article acknowledge by saying "This paper is dedicated to Prof Gopal Rao upon his promotion to Distinguished Professor Emeritus status. Prof Rao once remarked to one of us (CAF) that being at UMass Boston—rather than say at Harvard or Yale—allowed his career to excel. . UMass Boston brought him academic freedom that could not be found elsewhere. He worked on whatever he pleased, without pressure for high-dollar funding or worries over journals' impact factors. We offer this paper to Prof Rao in his own spirit. True science is founded upon the freedom to become fascinated by a simple pebble on a beach, whether it be polished or not, or whether it have any value at the local market."

We extend heartfelt gratitude to the *Asian Journal of Physics* for giving us the opportunity to pay our tribute to Prof Gopal Rao in this manner. Additionally, we wish to express sincere appreciation to all contributors who have generously shared their research findings, insights, and reflections with Prof Gopal

Rao. Your contributions not only celebrate Prof Rao's achievements but also underscore the pivotal role of mentorship in shaping the trajectory of scientific advancement.

Finally, we are grateful to Er Manoj, Er (Ms) Nidhi, and Ms Laxmi for all the hardwork they have done toward a successful edition of the special issue dedicated to Prof DVGL Rao. Last but not the least, a big thanks to Prof Vinod Rastogi for being a pillar of support during the entire period of editing this special issue.

As you immerse yourself in the contents of this special edition, we invite you to join us in commemorating the remarkable career of Prof DVGLN Rao and acknowledging the indelible imprint he has left on the scientific community. May this compilation stand as a fitting tribute to his enduring legacy.

Chandra S Yelleswarapu

D Narayana Rao

Guest Editors

About Guest Editors

Dr Narayana Rao Desai was born at Anantapur, Andhra Pradesh, India (1949) and his current designation is Honorary Professor, School of Physics, University of Hyderabad. He did his graduation and post-graduation in sciences from Sri Venkateswara University, India. He then completed the Ph D from IIT Kanpur. For a short while he worked at IIT Delhi, then moved to State University of NY at Buffalo, USA as a visiting scientist. He spent some time also at Spectroscopy labs, MIT, Cambridge; University of Massachusetts, Boston and Lowell, USA. He then joined the faculty of School of Physics, University of Hyderabad as a Reader in 1990, and became a full Professor in 1998.

23 Ph D students and several M Phil students have completed their work under him. Many students from other institutions too completed their Ph D work in his lab. He has nearly three hundred refereed research publications in international journals and presented an equal number in international conferences. He was awarded NRC (USA) Fellowship, UGC-BSR Faculty Fellowship and DAE Raja Ramanna Fellowship. He is a Fellow of the Academies of Telangana and Andhra Pradesh. He was also elected as the Distinguished Fellow of Optical Society of India.

He worked on several areas of spectroscopy and nonlinear optics: Microwave spectroscopy, Development of lasers, Fluorescence spectroscopy, crystal growth, Spectral Interferometry, Incoherent Laser Spectroscopy, Ultrafast Dynamics, Transient Grating Spectroscopy, Coherent Anti-Stokes Raman Spectroscopy, Four Wave Mixing, Z-scan, 1D and 3D Photonic Crystals, Nanoplasmonics, Surface Enhanced Raman Spectroscopy, Supercontinuum Generation, Green Synthesis of Nanoparticles, and Laser Direct Writing. Currently he is working on Antireflecting surfaces, Superhydrophobic surfaces, 1D Photonic structures.

Dr Chandra S Yelleswarapu is an Associate Professor in the Department of Physics at the University of Massachusetts Boston, where he has made significant contributions to academia and scientific research. He earned an M Phil degree from the University of Hyderabad, and a PhD in Physics with a specialization in Applied Optics from Alabama A&M University in 2001. Following his doctoral studies, Dr. Yelleswarapu pursued postdoctoral training at the University of New Mexico and later at the University of Massachusetts Boston.

Joining the faculty as an Assistant Professor in 2009, Dr. Yelleswarapu's scholarly achievements led to his tenure in 2015. He has consistently excelled in research, teaching, and mentorship. His research focuses on the convergence of nonlinear optics, photoacoustics, and quantitative phase imaging. Leading a dynamic

laboratory, Dr Yelleswarapu delves into fundamental research in these realms while striving to translate discoveries into tangible solutions for real-world challenges. He has initiated several groundbreaking projects during his tenure, including the development of the Fourier phase contrast microscope and the photoacoustic z-scan (PAZ-scan) technique.

Fourier phase contrast microscope exploits the thermotropic properties of nematic liquid crystals for phase contrast principle. PAZ-scan is a fusion of optical z-scan simplicity with the sensitivity of photoacoustic methods. It is particularly useful for investigating the absorption and thermal properties of materials, especially those that are opaque or have complex structures.

Collaborating seamlessly across disciplines with colleagues in Physics, Chemistry, Biology, and Psychology, Dr Yelleswarapu spearheaded projects aimed at designing efficient photoacoustic contrast agents for cancer/tumor imaging and developing user-friendly interfaces for quantitative biological analysis using digital holographic microscopy, among others. Presently, his research endeavors encompass exploiting plasmon coupling to enhance third-order nonlinear optical absorption, developing mobile lensless digital holographic microscopy for disease diagnosis, handheld photoacoustic sensors, and investigating the interaction of acoustic waves with liquid crystals.

His scholarly contributions extend beyond the laboratory, with 45 peer-reviewed research articles published in high IF journals and 4 patents, one of which is licensed for manufacturing and marketing. Dr Yelleswarapu's dedication to mentorship is evident through his supervision of graduate and undergraduate students, many of whom have pursued advanced degrees and successful careers in academia and industry, as well as hosting visiting scholars.

Dr. Yelleswarapu is committed to fostering diversity and inclusion in STEM fields, actively engaging underrepresented students in research programs and university-wide initiatives. He has served in various leadership roles, including Chair of the CSM Faculty Senate and membership in committees overseeing academic policies, discipline, and grievance procedures.

An active participant in scientific communities, Dr. Yelleswarapu contributes his expertise as a reviewer for top journals and grant proposals, as well as serving on editorial boards and organizing special issues. His dedication to advancing scientific knowledge and fostering interdisciplinary collaboration underscores his impact in the field of physics and beyond.

Vinod Rastogi

Editor

About Professor D V G L N Rao

Photo 1: Prof D V G L N Rao, UMASS, Boston, USA

Born on July 6, 1933, in a small town Pithapuram in Andhra Pradesh, Prof D V G L N Rao grew up in a community where scholarship was valued even when it did not translate to wealth or power. He graduated B Sc (Honours) with a major in Physics and minors in Mathematics and Chemistry, with top score among all science and math majors earning the prestigious gold medal. In 1954 he got his Master's degree from Andhra University, with a thesis on measuring dielectric constants of organic liquids and theoretical studies of induced dipole moments for interpreting the experimental results. For this work he built the experimental arrangement from scratch including silver coating of inner walls of a glass cell, made in the glass blowing shop, serving as capacitor plates. In 1958 he was awarded the Doctor of Science degree, from Andhra University, for a thesis on microwave cm and mm dielectric constant and absorption measurements of organic liquids with supporting theoretical studies of hybridized valence electrons.

Prof Rao was a recipient of Full bright travel grant and spent two years in Prof Walter Gordy's Microwave Labs at Duke University as a Postdoctoral Associate, studying electron spin resonance of single crystals. He returned to India and spent a few years at Andhra University, Visakhapatnam, and Solid State Physics Laboratory, Delhi. However, just before he left Duke he came to know about the invention of the laser. He was fascinated by all the new optics and novel physics possible with such intense coherent source. Aiming to join Noble Laurate Prof Nicolaas Bloembergen's lab at Harvard University, but not having prior experience with new lasers, he succeeded in getting a job as a Research Physicist in a Laser company in the Boston area. Within a year he published a paper on Laser induced resistivity changes in Silicon wafers. In addition, he wrote a proposal for an innovative basic physics experiment using intense laser light and sent a copy to Prof Bloembergen seeking a postdoctoral position in his lab. Prof Bloembergen immediately responded with a note saying they have also been thinking about it, inviting Prof Rao to join his group. He worked on Nonlinear Optics using both high power lasers for Stimulated Brillouin Scattering and Spontaneous Brillouin Scattering with low power single frequency gas laser.

With the advice of Prof Bloembergen, Prof Rao joined UMass Boston as an Associate Professor in 1968. He set up a research lab quickly using seed money from UMB and succeeded in NSF funding for a project on Nonlinear Optics of Liquid Crystals, publishing the first research paper in 1970 involving under-graduate students in the research enterprise. Inspite of the promise of graduate programs, with the budgetary constraints of a state school, there was no hope in the near future. Instead of getting discouraged, he saw this as a challenge and an opportunity to make a difference in teaching as well as creative research work even without a graduate program. He published a paper on the self-focusing of laser light in a liquid crystal in Applied Physics Letters, November 1973, which was selected by the American Physical Society for press release at the annual meeting in Chicago in 1974. He was invited to write a popular version published in the research frontiers section of Physics Teacher. Despite such significant progress, his NSF grant was not renewed due to lack of master's program. Even though he had to go through a lean tough period, he never gave up his passion

for professional activity, always believing that good teaching/research go together and UMB students deserved good teachers and he cannot be one unless he is at the forefront with research activity. In 1980 after a long wait, UMass Boston started the Master's program in Applied Physics with a thesis or internship component for opportunities of work in a real-world industrial environment. He started teaching a graduate course on a lab-based laser optics course so that the students can grasp some of the new theoretical concepts of Gaussian beams, coherent light, etc with hands-on experience in the lab with the actual experiments in sync with the lectures. He also developed an advanced Laser Optics graduate course again with a lab as a follow-up. Along with Chandra, he is writing a book with emphasis of the innovative experiments developed for graduate and/or senior undergraduate laser optics course to be published by Springer Nature soon.

Photo 2: Prof D V G L N Rao when he was attending the centenary birthday celebration of Professor Nicolaas Bloembergen. Students and postdocs gathered at Harvard University campus in March 2020.

His efforts at continued research activity resulting in a stream of publications were rewarded by Battelle (Defense contracting agency) with a modest initial short term contract of $40,000, with the additional privilege of using the in house lab equipment at US Army Natick Labs which included state of the art Picosecond pulsed Nd:YAG frequency-doubled green laser system. With one graduate student working full-time they demonstrated rapid progress publishing a seminal paper in *Applied Physics Letters* on third-order nonlinearities of porphyrins within just a few months. He was able to attract UMB's first big research grant of half a million dollars for three years from US Army Research. The support continued for about twenty years at an average rate of a hundred thousand for work on Laser Eye Protection. He had an Adjunct Professor appointment at UMass Amherst and Lowell campuses; one of his graduate students got a Ph D at Amherst and a second one at Lowell. He published on a variety of topics- stimulated Raman and Brillouin scattering, self-focusing, optical power limiting, etc. His inherent preference was always to work on basic concepts with tabletop experiments

Photo 3: Prof D V Rao working on setup in his lab (left) and teaching experimental techniques to undergraduate students (right).

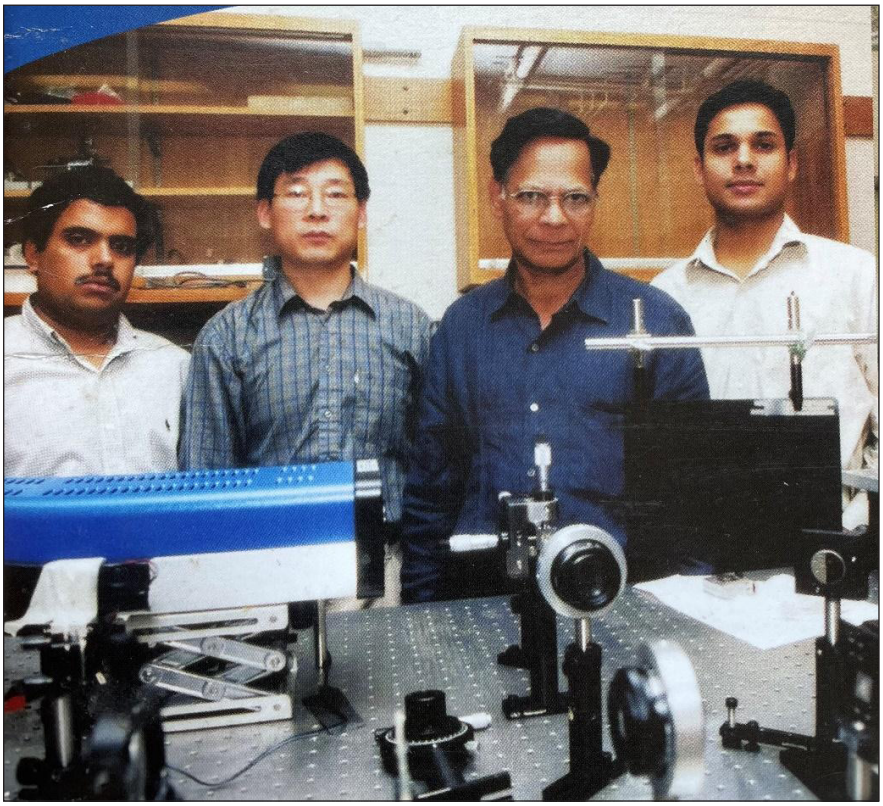

Photo 4: Prof D V Rao with postdoctoral fellows (Chandra Yelleswarapu, Pengfei Wu) to his right and then graduate student Sri-Rajakasekhar Kothapalli to his left. Photo is adapted from cover photo of UMass Boston Fiscal Year 2006 Annual Report on Research and Programms.

using inexpensive equipment- nonlinear optics with hundred dollar He-Ne milliwatt lasers and started experimenting with the biological material Bacteriorhodopsin, a non-conventional nonlinear optical material; the nonlinearity is induced by the laser light and intensity-dependent, values reaching one esu, compared to a

traditional nonlinear material like carbon disulfide twelve orders high with a value 10-12. He published over twenty research papers and four book chapters involving basic physics and significant applications of optical Fourier processing for breast cancer diagnostics, medical image processing exploiting diffraction holography, nonlinear absorption, etc. His group also studied a variety of azobenzenes for low power nonlinear optics-basic physics as well as applications for optical power limiting.

He mentored several postdoctoral associates and graduate students. His postdocs used to stay long periods upto 6-7 years. His philosophy was to provide general guidance and direction but try to inspire them to think for themselves. He developed successful collaborations with both academic and industrial labs: Breast Imaging center, Emory University Medical School; Department of Radiology, UMass Medical School; Department of Polymer Science, UMass Amherst; Departments of Physics/Chemistry Advanced Materials Research Lab, UMass Lowell; Biology department, UMass Boston; Moffitt Cancer Research center, University of South Florida; Cape Cod Research, Falmouth, MA; Ocean Nanotech, Arkansas; Nanomaterials Science Team, US Army Natick Soldier Center; Rowland Institute of Harvard University. He was able to attract research funding from several agencies: NSF, NIH, US Army, DARPA, SBIR, Raytheon, Battelle, Technology and Research of Singapore- Biomedical Research Council. He presented invited talks at many national and international conferences and seminars at many domestic and foreign institutions. He organized and Chaired the session on Bacteriorhodopsin photonics at the New Orleans APS meeting, March 2008. He served the Department as Chair for over two years and as Graduate Program Director for over fifteen years, significantly contributing to the MS Applied physics program recruiting good domestic and foreign students, guiding many of them for their theses. He has been serving as a Visiting Professor at Sathya Sai Institute of Higher Learning; taught a course on Lasers during 2003 and collaborate with them in research projects and grantsmanship. He gave a few lectures at Gitam University, Visakhapatnam, and holds the title of Honorary Professor of Physics. He published over 120 papers in prestigious journals like Nature, Physical Review Letters, Applied Physics Letters, Optics Letters, Nano Letters, Physical Review, etc, and 7 book chapters. His group was granted a dozen patents and the one on Phase Contrast Microscopy is recently licensed to Grey Slide Imaging Inc., Ottawa, Canada, for marketing the technology.

Prof Rao was listed as one among six in the UMASS-wide system for work relating to intellectual property. His group was displayed on the cover of the UMB 2006 Annual Report on Research and Sponsored Programs. He was listed among top ten professors (in no particular order) in the student new paper Mass Media by the only student survey conducted in 30 years. His work is cited in Nature Research Highlights December 2005, Physics Review Focus January 2006, Photonics Spectra March 2006, CERN Courier, IOP Magazine 2006; displayed on UMB website front page December 2004/January 2005. In 1992 he was awarded the Chancellors Distinguished Scholarship by UMass Boston. In 2006 UMass Boston awarded him Distinguished Professor (one among 6 out of about 700 faculty). In 2010 Prof Rao was elected as Fellow of the American Physical Society, Laser Science Division, the citation reads “in recognition of a long record of significant contributions to the nonlinear optics of organic materials and their application to optical power limiting, Fourier Phase Contrast Microscopy and Medical Image Processing.” He achieved all this without a Ph D program in the department.

After retirement in 2017, as Distinguished Professor Emeritus he still has some professional acitivty mostly in efforts relating to technology transfer of patents to real gadgets. Prof Rao is now spending his time on Science and Spirituality and presented papers at International Vedantha conferences organized by the Philosophy Department, Miami University, Oxford, Ohio. Most of the participants are academic philosophers working on Vedantha; there were a few faculty from Physics, Chemistry, Mathematics, Computer Science; late Prof George Sudarshan was an active participant. He presented a paper on Quantum Reality, Spiritual Concepts and Modern Optics Experiments at the conference on Quantum Reality and Theory of Shunya,

December 9-10, 2016, Delhi, organized by Prof S R Bhatt (Sanskrit and Philosophy, Delhi University)- there were only about thirty invited participants; Physics, Chemistry, Computer Science, Philosophy faculty, Hindu and Buddhist religious institutional affiliates. The proceedings were published by Springer Verlag, Delhi. In his view, Quantum Physics is the science of contemporary spirituality providing experimental evidence to spiritual concepts. The QBSM (Quantum Bayesian- QP based on subjective Bayesian probabilities instead of Schrodinger's traditional frequentist probabilities) pioneered by his colleague Chris Fuchs presents the ontic and epistemic aspects strikingly similar to the concepts in Hindu Upanishads views. There are also similarities with Buddhist Madhyamika philosophy.

Photo 5: Prof. D V Rao with his postdoctoral research associates pose with the NanoTech Brief's Nano50 award: (from L to R) Dr Pengfei Wu, Prof D V Rao, Dr Francisco Aranda, and Dr Chandra Yelleswarapu.

Photo 6: Prof D V Rao (centre) and his wife Dr Lalitha Rao (on his right) with Prof Vladilen Belousova (extreme left), Prof Inna Belousova (second from left), and Dr Alexander Gorshkov (extreme right) Conference Marketing Manager, at the International conference on Laser Optics, St. Petersburg, Russia 2014.

Photo 7: (from left) Prof D V Rao, Prof Inna Belousova, Dr Lalitha Rao and Prof Tanaka from Kyoto University, at the International conference on Laser Optics, St. Petersburg, Russia 2010.

Prof Rao and his wife, Dr Lalitha Rao, are keen on helping people in need. They funded a project to screen poor rural women for cancer in several villages near Hyderabad, in collaboration with the Sri Satya Sai Baba Seva organization and The Indo American Cancer Institute and Research Center of Hyderabad. Given profound interest in education, they set up endowments for annual scholarship awards at UMass Boston (minority undergraduate student in Physics), A V N College, Visakhapatnam for an undergraduate student in Physics for an innovative project, High School in Pithapuram (graduating student for the innovative project). They also funded an endowment for annual award to the faculty member in all sciences who publishes the best research paper in the year.

Chandra S Yelleswarapu,
University of Massachusetts, Boston, USA

D Narayana Rao,
University of Hyderabad, Hyderabad, India

Appreciation

Bala Sundaram

It is my great pleasure to contribute to this special issue of the Asian Journal of Physics dedicated to celebrating the research of Prof D V G L N Rao (Gopal Rao). The other articles focus mainly on his scientific contributions while I was asked to write about Gopal Rao's contributions as a long-time member of the Department of Physics at the University of Massachusetts Boston. At the time of Gopal's retirement, he had been at the university for over 48 years which was almost the entire lifespan of the campus itself. I tried to check with more senior colleagues about finding some visuals of his early days on the campus but the photograph shown, taken in 1977 for the departmental bulletin board, was the closest I could get.

After reading for his basic and advanced degrees at Andhra University, Dr Rao held post-doctoral positions in academia, both at Andhra and Duke Universities, and then spent a few years in corporate research before joining UMass in 1968. I like to think that his functioning in both these worlds resulted in his entrepreneurial bent and efforts later in his career. At UMass, he started as an Associate Professor and quickly achieved full Professorship and then, later, assumed the mantle of Department Chair. He was an important catalyst for the start of an Applied Physics graduate program and served as its Director at several points of his career. It was in this role that I first met him when I joined the Department as an externally recruited Chair in 2006.

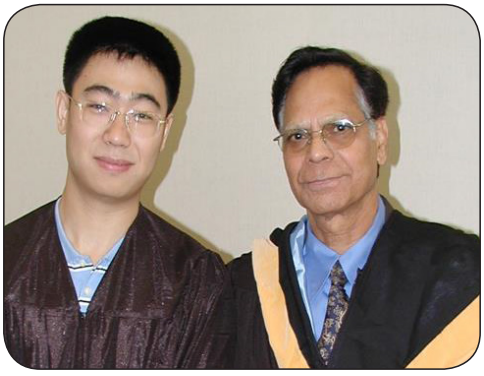

Photo of Prof Rao (right). with a Masters' degree mentee – 2006 Commencement exercise.

At the time of my arrival, the department was in a rebuilding phase after several years of faculty attrition due to retirements. It was immediately apparent to me that Gopal's tenure at the institution exemplified excellence in all facets of academic functioning. In particular, his ability to consistently contribute significantly to research at the forefront of his field of nonlinear optics, under far from ideal conditions, set him clearly apart from his peers both locally and nationally. It was also notable that he was regarded as one of the top experimentalists in his area, reflected in the fact that his work had impacted developments in other (even unrelated) fields. Despite all this activity, Gopal Rao was also the consummate University citizen over the years, ready to respond to the needs of the department and institution. He was an excellent teacher and research mentor to students at all levels and had successfully guided post-docs and visitors into independent research

careers. In fact, he was selected as a top instructor by a student newspaper, popularity that is usually hard to come by. Based on this total assessment, I was more than delighted to nominate Dr Rao for a Distinguished Professorship soon after my arrival, a nomination which was approved and which I count among my successes at the institution.

I was also intrigued by the evolution of Gopal Rao's scientific interests over the years. Starting from more traditional issues in nonlinear optics and spectroscopy, he moved to the characterization and applications of the nonlinear optical properties of novel materials, most notably biological proteins such as bacteriorhodopsin. This evolution in his interests coincided with the expanded use of lasers for all aspects of experimentation in his field. In general, this had led to large increases in the cost of executing cutting-edge research as well as the need for support facilities and personnel. In contrast, Gopal Rao's work over the years highlights ingenuity which was better suited to the more modest facilities available to him. In my view, an example that amply illustrates this trait is his work on 'slow light'.

The manipulation of the speed of light followed the discovery of a 'macroscopic coherent state of matter', namely the Bose-Einstein condensate. The original experiments were performed at the Rowland Institute of Harvard University in 1999 and were a multi-million-dollar effort. After that, there had been several attempts made to arrive at a cheaper realization, one not involving extensive fabrication or low operating temperatures, which would be better suited to the applications, such as in communication, envisaged for the phenomenon. Rao, together with a single post-doc, showed that using a biological film allows for exceptional results and versatility, results published in a paper titled "Controllable snail-paced light in biological bacteriorhodopsin thin-film". The low-cost of the material taken together with the room-temperature operating conditions make this an ideal candidate for moving the basic science into the realm of technology, a fact recognized by Nature and other publications that highlighted the work.

This latter aspect illustrates another key feature of Gopal Rao's work which has always bridged basic and applied physics. This motivation peaked with a number of patent applications, grants and collaborative ventures emphasizing devices and applications. Key among these are the uses of ingenious adaptive optics for mammography and phase contrast microscopy as well as the use of a thin film of bacteriorhodopsin to regulate and attenuate the intensity of transmitted light. An award from Nanotech Briefs for work with periodically aligned carbon nanotubes testifies to a more wide-spread recognition of the technological impact of Gopal Rao's research. Though I have drawn my examples from my own time in the department, the trends I have cited are reflected in the entire body of Gopal Rao's work. On our campus, Gopal was a pioneer in venturing into the intellectual property domain and, due to his intense perseverance, he was recently able to arrive at a licensing agreement for one of his patents on an inexpensive phase-contrast microscope.

While department chair, I also nominated Gopal for a Fellowship of the American Physical Society, for which I solicited letters of support. Early in his career, Gopal spent time in the research group of Prof Nicolas Bloembergen at Harvard University, so I wrote to him asking for a letter. As part of his response, Prof Bloembergen sent a brief email in which he stated that he had "...always assumed that he (Gopal) had received that distinction decades ago". This sentiment was aligned with the belief of my colleagues and me that this honor was indeed long overdue. This proved a persuasive argument as the American Physical Society agreed with this assessment.

In conclusion, I did want to assert that it wasn't just Gopal who enhanced the well-being of the departmental community but also his wife Lalitha. Many in the department have fond remembrances of being entertained warmly at their home. Indeed, their campus impact continues as they both recently established a scholarship fund to assist students from under-represented groups while pursuing a degree in physics. Overall, Prof D V G L N Rao has left an indelible impression on the department and institution he served for nearly five decades.

Author's Information

Dr Bala Sundaram obtained Ph D in 1985 from the university of Pittsburgh He is a Professor and former Chair of the Physics Department at the University of Massachusetts Boston. His research interests are in nonlinear dynamical systems, classical and quantum chaos, and mathematical biology among other areas. He is currently the Vice-Provost for Research and Dean of Graduate Studies.University of Massachusetts - Boston

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Department members and families come together at Dr Rao's retirement party.