Prof. Devendra Lal: Glimpses of his Research

Prof. Devendra Lal, Fellow of the Physical Research Laboratory, Ahmedabad (India) and Professor at the Scripps Institution of Oceanography, San Diego, California (USA) passed away on 1st December, 2012, at his residence in San Diego, California, at the age of 83. Prof. Lal was a doyen of cosmic ray physics and earth and planetary sciences and a distinguished mentor. He had a wide range of scientific interests spanning diverse areas of Earth and Planetary Sciences, from the earth's mantle to the Moon and beyond. The novel ideas developed by Prof. Lal with his students and colleagues in the field of *Cosmogenic Nuclides in Earth and Planetary Sciences* led to seminal and innovative contributions that ushered new knowledge to characterize basic processes in various planetary reservoirs.

Lal in discussion with Prof. B. Peters

Prof. Lal joined the Tata Institute of Fundamental Research, Mumbai in 1949, after completing his Masters in Physics from the Banaras Hindu University, a move that laid the foundation for his prolific research career. His early research at the Tata Institute of Fundamental Research with Profs. H. J. Taylor and B. Peters on cosmic rays provided insights into the nature and properties of elementary particles and their interactions much before the dawn of high energy accelerator era. The discovery of radiocarbon (^{14}C) in the environment by Prof. W.F.Libby and his colleagues was the major turning point in the research interests of Profs. Peters and Lal. These scientists recognizing that cosmic ray interactions with atmospheric constituents would also produce a suite of radionuclides in addition to ^{14}C, such as the long lived ^{10}Be, shifted their research focus to investigations of production rates of various cosmogenic nuclides in the atmosphere and exploit their applications in Earth Sciences. This resulted in the discovery of a number of cosmogenic nuclides in earth surface reservoirs during 50's and 60's and a series of pioneering and bench mark publications on their production and applications that opened a completely new field of research in earth and planetary sciences. Among the various cosmogenic nuclides discovered by the TIFR group, mention must be made of ^{10}Be and ^{32}Si two nuclides the detection of which required major advances in analytical and detection techniques because of their extremely low concentrations in earth surface reservoirs. First measurements of ^{10}Be by the TIFR group was made in rain water and deep-sea sediments at about the same time as it was independently discovered by Prof. J.R. Arnold and his group at the University of California, San Diego also in deep sea-sediments. Prof. Lal commenting on the detection of ^{10}Be wrote years later " *For me and my colleagues it (discovery of ^{10}Be) demonstrated that we could do good science in India if we had confidence in ourselves"*. The detection and measurement of ^{32}Si was even more challenging; Prof. Lal jointly with Prof. E.D.Goldberg and colleagues of the Scripps Institution of Oceanography overcame these through novel experimental approaches during his visit to SIO. The ^{10}Be project at TIFR grew in strength and Prof. Lal as a part of his continuing foray into studies of cosmogenic nuclide applications, established the first National Radiocarbon Laboratory at TIFR primarily to determine the chronology of ancient cultures of India and to learn about the march of civilization in this part of the globe.

On the personal front, Prof. Lal courted and married his colleague Ms. Aruna in 1955. Soon after their marriage, Prof. and Mrs. Lal along with scientists of the ^{10}Be project undertook a major field campaign to Kashmir to process tons of snow for the detection of ^{10}Be. Ever since Mrs. Aruna Lal had been the pillar of strength and

Lal, Honda and Arnold with their spouses in a 1989 get-together. The "wall paper" behind them depicts Apollo 11 sample analysis protocol.

support for Prof. Lal's research career and achievements and an affectionate member and caretaker of his group.

The scope of Prof. Lal's research widened considerably during the early 60's following his joint initiatives with Profs. J.R. Arnold and M. Honda from the University of California, San Diego to include topics on prehistory of cosmic rays and planetary evolution based on in-depth studies of signatures of cosmic rays in meteorites. These studies not only retrieved the paleointensity of cosmic rays in the galaxy through measurements of cosmogenic nuclides in meteorites but also established the potential of such records to determine the exposure history of meteorites in space. Prof. Arnold years later wrote "the *collaboration among Honda, Lal and myself has been one of the happiest and most fruitful of my life*".

It was around this period that a new field on nuclear tracks in solids and their applications were being developed by Profs. R. L. Fleischer, P. B. Price and R. M. Walker. Prof. Lal was fascinated by this new development and was keen to explore its applications to investigate the evolutionary history of terrestrial and extraterrestrial objects. This led him to invite Prof. Price to TIFR to get a first hand knowledge of the field. During the next decade Prof. Lal and his group made major advances in the field of nuclear tracks and applied them successfully to researches on properties of cosmic rays as recorded in tiny silicate grains of meteorites and moon samples (Fig.1)that include the composition and energy spectrum of heavy iron group particles (Z>22) in galactic cosmic rays during the past, the exposure history of lunar grains to solar flare particles, and lunar regolith dynamics at the Apollo and Luna landing sites.These investigations not only provided new knowledge on several Planetary, Solar System and Astrophysical processes but also laid foundation for extensive research on extra-terrestrial samples in India. The lunar research programme of Prof. Lal and colleagues at TIFR and later at PRL, two of the selected laboratories worldwide to receive moon samples from NASA, focused on studies of solar cosmic ray irradiated grains in the moon samples as they hold clues to processes leading to planetary evolution; a study that was prompted by their earlier discovery of such grains in gas rich meteorites.

Prof. Lal made a major career move in 1972; he shifted to the Physical Research Laboratory (PRL), Ahmedabad as its Director succeeding Prof. Vikram Sarabhai. At PRL he initiated new programmes in Earth and Planetary Sciences, and Astronomy and was responsible for the establishment of the Mt.Abu infra-red Astronomical Observatory. Prof. Lal relinquished the position of

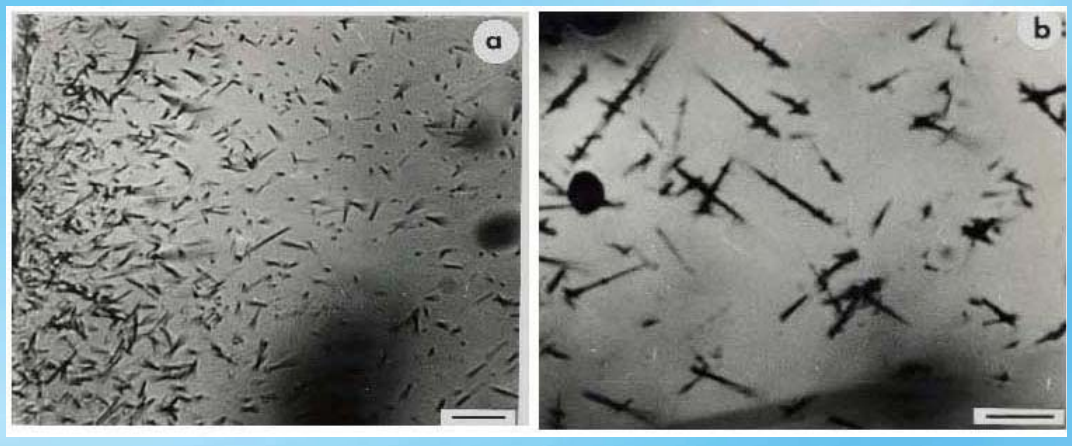


Figure 1: Nuclear tracks in silicate grains due to solar and galactic cosmic ray heavy ions

Director 1983 at the age of 54 and pursued his research interests by dividing his time between PRL and the Scripps Institution of Oceanography, University of California, where he served as a full time Professor since 1987. He continued his research through active participation and mentoring at both these research institutions till he passed away.

In the field of Earth Sciences, the discovery of several cosmic ray produced isotopes of widely different nuclear and chemical properties in the early 60's laid the foundation for Prof. Lal and his colleagues at TIFR, PRL and Scripps to exploit their applications to time and tag various processes in the surface reservoirs of the earth; large scale atmospheric circulation, elemental scavenging from the atmosphere and oceans, hydrology of oceans and sub-surface waters, specifically the determination of "ages" of water masses and their movement and nutrient dynamics in the sea. Prof. Lal's ambition to fully exploit the application of ^{32}Si to investigate global ocean circulation and particle dynamics in the sea was fulfilled when he along with his colleagues from PRL painstakingly measured its distribution in world oceans jointly by Profs. H.Craig of Scripps and K.K.Turekian from Yale University, as an integral part of the Geochemical Oceans Sections Study, a major international oceanographic initiative designed to track deep water movements and their rates. The studies on particle dynamics in the oceans later led Prof. Lal and his group to explore the use of biogenic opal in marine sediments to retrieve past records of surface ocean biogeochemistry and climate change.

Studies of cosmogenic nuclides in earth and planetary sciences took a major leap with the advent of Accelerator Mass Spectrometry, a technique that could measure extremely low concentrations of long lived cosmogenic isotopes. This new technological advance formed the basis for Prof. Lal to conceive and establish another new and major area of cosmogenic nuclide applications based on *in-situ* produced isotopes, particularly ^{10}Be and ^{26}Al to determine exposure history of rock (glacier) surfaces. Prof. Lal's contributions to this field through calculations of nuclide production rates and novel experimental approaches opened an avenue to determine erosion rates and exposure ages of rocks. This approach often used by earth scientists places geomorphologic studies on a quantitative footing for the first time.

Prof. Lal's active involvement in promoting excellence in scientific research, particularly in the field of Earth and Planetary Sciences is evident from the large number of students from India and USA he has mentored for their Masters and Doctoral research. Four generations of students have benefited from his tutelage, many of whom continue to pursue a research career and contribute to the global school in Earth and Planetary Sciences. Mrs. Aruna Lal, on her part was concerned about science education in children and both of them were keen to support schools and educational practices that can inculcate in children scientific temperament and enhance their curiosity about nature. A classic example of this is the way by which small school going children were involved in recovering bits and pieces of a meteorite that fell over an area of about 50 square kilometers in the Dhajala village of Surendranagar district, Gujarat. Search parties involving students and teachers of neighbouring villages resulted in an efficient collection of this precious meteorite. Mrs. Lal's wishes, however could not be put in

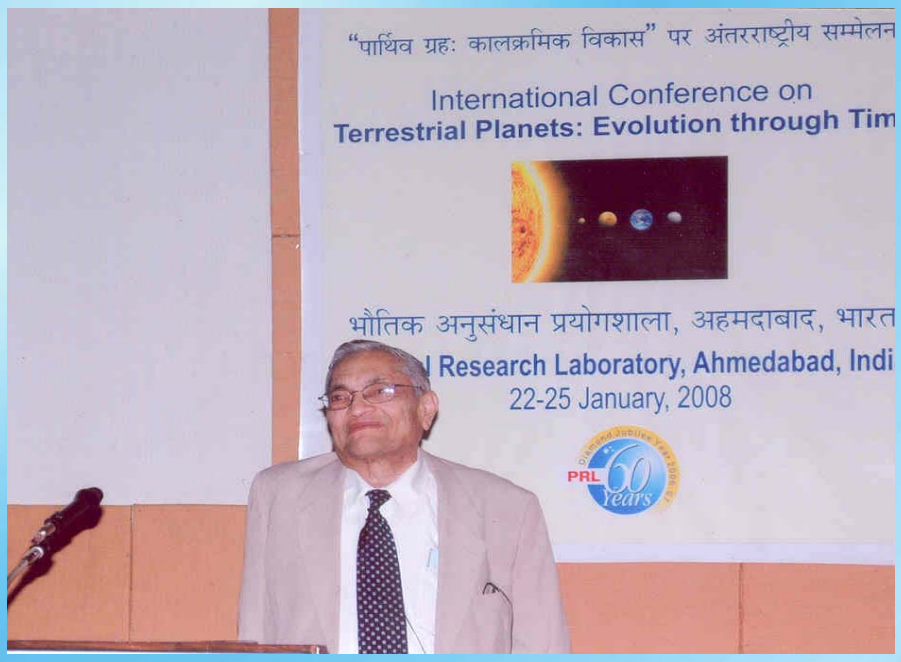
An organized search for Dhajala meteorite samples by students and teachers enthused by Prof. Lal

practice as she passed away in 1993. Her sad demise devastated Prof. Lal. In her memory he established the Aruna Lal Trust, administered through PRL, for providing scholarships for selected high school students to pursue college education in the science stream. The Trust also encourages young scientists who have made outstanding contributions in Earth and Atmospheric Sciences through the "PRL Award".

The professional achievements of Prof. Lal are in no small measure due to Mrs. Aruna Lal's sustained emotional and intellectual support. To quote from Prof. Price's article 'A friendship with Lal' : *What brings order into his (Prof. Lal's) life and keeps his imagination from running away from him is Aruna ----------The two of them operate very effectively as a team--------- and Aruna is largely responsible for Lal having achieved so much*

The hallmark of Prof. Lal's research has been his wholesome approach of combining both theoretical and experimental studies to probe planetary physical and chemical processes and to determine their time scales. His seminal work on the calculations of cosmogenic nuclide production rates in various Earth reservoirs and other solar system objects and their validation through innovative experiments laid the foundation and subsequent development of the field of "*Cosmogenic Nuclide Applications in Earth and Planetary Sciences"*. He has more than 200 publications in scientific journals, and about 100 publications in books, encyclopedia and conference proceedings. Prof. Lal's research and publications bear ample testimony to his interdisciplinary approach to scientific investigations; they combine inputs from the fields of cosmic rays, nuclear physics, earth and planetary sciences and astrophysics.

Prof. Lal's research contributions have won him several national and international recognitions. He is a Fellow of the Royal Society (1979), Foreign Associate of the National Academy of Sciences, USA (1975), Founder Fellow of the Third World Academy of Sciences, Fellow of the American Association for the Advancement of Science and Fellow of all the three science Academies of India. He is a recipient of the several awards that include Bhatnagar Prize (1967), Goldschmidt Award (1997) and Sir C.V. Raman Birth Centenary Award (1996-1997). Prof.Lal is also a recipient of the civilian award "Padmashri" bestowed by the Government of India. The important positions Prof.Lal has occupied in International Scientific Organizations also bear testimony to his scientific stature. He was the President of the International Association for Physical Sciences of the Ocean (IAPSO) during 1979-83 and the President of the International Union of Geodesy and Geophysics (IUGG) during 1983-1987.



Prof. Lal delivering inaugural lecture at a conference at PRL.

It is difficult to come to terms with the reality that Prof. Lal is no more. He will be sorely missed by all those who knew him. He was a versatile and distinguished colleague, an illustrious Earth and Planetary Scientist, a great teacher and mentor. His life and work will be an inspiration for the new generation of scientists to pursue high quality research and take forward his intellectual and child like curiosity.

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