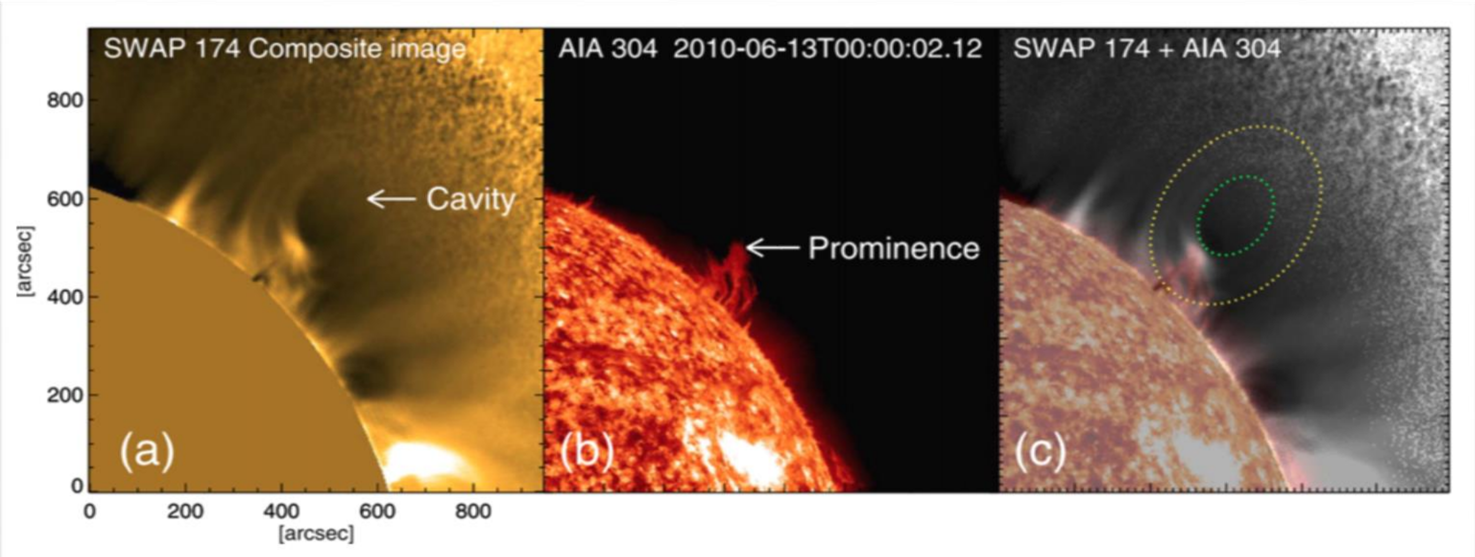
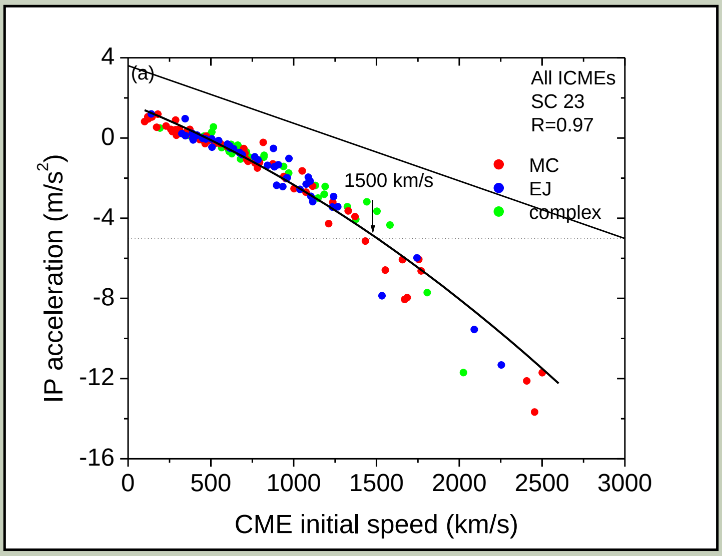
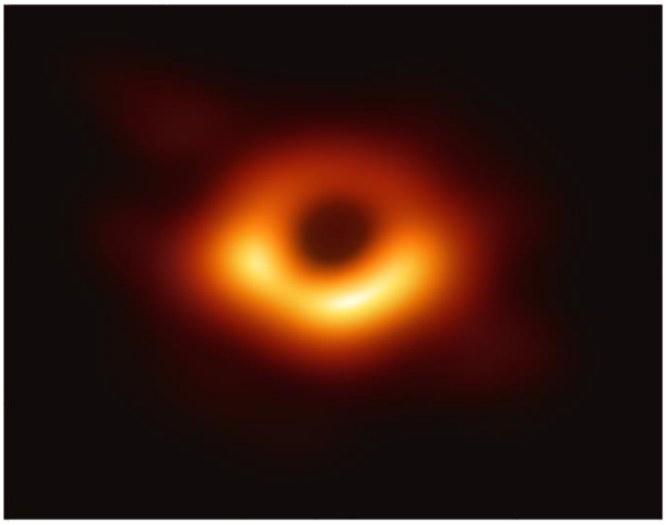
PRL NEWS – THE SPECTRUM

JUNE 2019







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Photographing a black-hole

(Jitesh R. Bhatt, Arun Kumar Pandey)

Jitesh Bhatt

An early foreshadowing of the concept of black holes (BHs), British scientist John Michell notes that light can't escape from objects that are extremely massive [1]. It was Einstein in 1915, who gave the general theory of relativity (GTR), which describes how mass act on spacetime, producing gravity. The theory eventually leads to the realisation that matter could be packed into infinitely warped regions of space. According to GTR, at the centre of a BH, there might be a singularity where space-time curvature can be infinite. For a static BHs, this singularity could be a point-like, for a rotating black-hole can have a ring-like structure in the plane of rotation. For a static black-hole with mass M, exactly $RS = 2GM/c^2$ distance from its singularity, the spherical surface is called event-horizon. Event-horizon is one of the defining feature of a black-hole and matter can only pass inside it. Nothing, even light, can get out of event-horizon. Typical size of the event-horizon for a black-hole of mass around one solar mass is around 3 Kms. In 1916 during World War-I, astronomer Karl Schwarzschild publishes a solution to Einstein's equations for general relativity near a single spherical mass [2]. Singularities in that solution, points where the mathematical results have infinite values, are an early sign of BHs. In 1939 Robert Oppenheimer and Hartland Snyder describe the formation of gravitationally collapsed structure (what we call today a BH), under the weight of its own gravity [3]. In 1958, Finkelstein and Charles W. Misner found the gravitational kink, a topological defect in the gravitational metric, whose quantum theory could exhibit spin 1/2. The simplest kink exhibited an easily understood event horizon that led him to recognise the one in the Schwarzschild metric and eliminate its coordinate singularity [4]. The term "black hole" (BH) was coined in 1967 by American physicist John Wheeler [5]. Later in 1974, Stephen Hawking concludes that BHs are not completely black. Instead, they emit a faint haze of particles, known as Hawking radiation [6]. It was almost one century after the first theoretical prediction of the BHs, a news breaks that ripples in spacetime called gravitational waves, generated by the collision of two BHs, were detected for the first time by the Advanced Laser Interferometer Gravitational-Wave Observatory (LIGO) in 2016. And recently on 10 April 2019, the Event Horizon Telescope (EHT) team has for the first-time revealed images of the super-massive BH at the centre of M87 (Virgo A) galaxy [7].

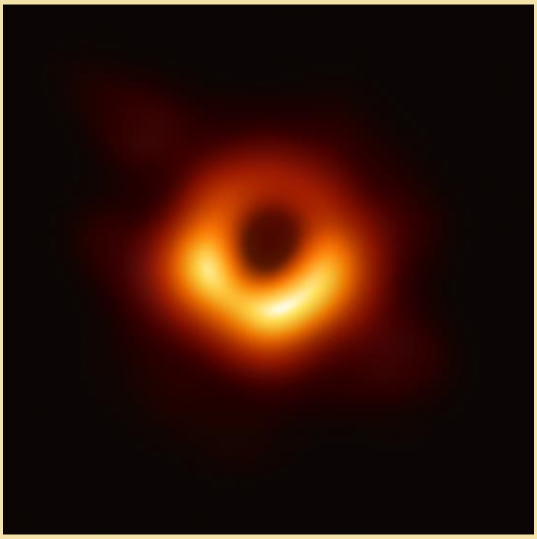

Figure Caption: The first image of a black hole obtained by EHT at the centre of M87. (© Event Horizon Telescope Collaboration)

So far, the astronomers have to rely only on indirect observations to detect a black-hole where the effect of its strong gravity can be seen. One of the very strong, albeit indirect, evidence came from the accretion disk studies. When gas is falling onto a compact object like a neutron star or a black-hole, due to angular momentum conservation they form a disk like structure. In the vicinity of event-horizon the gas orbits with a very high speed and due to the viscosity, temperature of the inner part of the disk can become very high and it can emit vast amount of electromagnetic radiation mostly in X-rays. In this process almost up to 40% of rest-mass energy of the gas can be emitted. In nuclear fusion only around 0.7% of rest-mass energy can be emitted. These high luminosity X-ray sources are usually accompanied by highly collimated jets which are also a consequence of angular-momentum conservation has been observed [8].

M87 galaxy is about 53 million light-years away from the earth with a supermassive accreting black-hole at the core. The black-hole has around 6.5×109 solar mass with the Schwarzschild radius around 5.9×10-4 parsec (1.8×1010 kms). To resolve an object of the size of 5.9×10-4 parsec from such a far distance require a telescope with diameter as big as the diameter of the earth. Event-Horizon-Telescope (EHT), a global very long baseline interferometry array of eight telescopes, located in America, Europe and South-Pole (Asia & Africa not included), observing at a radio wave length, reconstruct event-horizon-scale images (see Fig.1) of the supermassive black hole candidate in the centre of the giant elliptical galaxy M87. Local atomic clocks are required for each antenna in the array to register time when the data is received. These data then is correlated with the data from other antennas that recorded the same radio signals by synchronising with the atomic clock. From this data one needs to reconstruct the black-hole image which is like solving a jigsaw puzzle that requires a very complicated algorithm. In the image shown above, there is a bright ring of size 42±3μas (micro-arc-second) around a dark spot at the centre. This is because of the reason that of a high gravity around the black hole which bends the light. This is is consistent with expectations for the shadow region 2.6×RS as predicted by general relativity [7]. The asymmetry in brightness in the ring can be explained in terms of relativistic beaming of the emission from a plasma rotating close to the speed of light around a black hole. Due to the black hole's gravity light gets bent around it and creating the photon ring as predicated by the theory. Overall, the observed image is consistent with expectations for the shadow of a Kerr black hole as predicted by general relativity. This long-sought image provides the strongest and direct evidence to date for the existence of supermassive black holes. This opens up a new window to study of physics near black-hole event horizon.

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Evolution of Coronal Cavity from Quiescent to Eruptive Phase Associated with Coronal Mass Ejection *(Ranadeep Sarkar, Nandita Srivastava, Marilena Mierla, Matthew J West, and Elke D'Huys)*

Violent eruptions in the solar atmosphere, called Coronal mass ejections (CMEs), often have a severe impact on the space weather of Earth. Predicting the onset of CMEs is critical for predicting the space weather of Earth; however, it remains one of the most challenging problems in solar physics. It essentially requires a clear understanding of the physical processes leading to the triggering and initiation of CMEs. Observing the development of coronal cavities in lower coronal regions can provide intriguing clues to the formation of CMEs. In this work, we have tracked the evolution of a solar coronal cavity (see figure) from a quasi-static equilibrium in the lower corona to its eruption into the interplanetary space using multi-vantage point observations (SDO/AIA, PROBA2/SWAP, STEREO/EUVI, and SOHO/LASCO). Our study reveals that the initiation of filament-associated CMEs can be predicted well in advance by monitoring the evolution of the cavity above the filament.

Ranadeep Sarkar

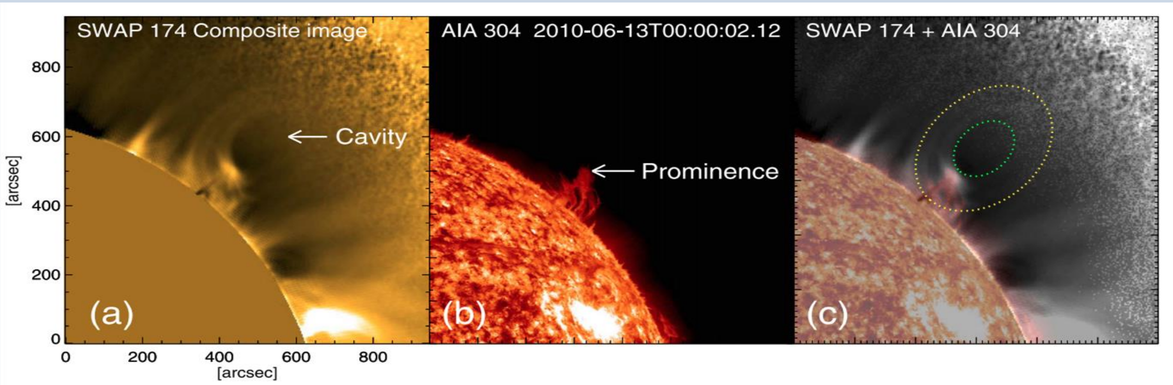


Figure 1: Observations of the coronal cavity as viewed in SWAP composite images (a) and the associated prominence structure as seen in the AIA 304Å channel (b). The superimposed images of the cavity morphology and the prominence structure as depicted in panels (a) and (b) are shown (c). In panel (c), the background image in grayscale represents the cavity morphology as depicted in panel (a), and the foreground image in AIA 304 Å color scale represents the prominence structure as shown in panel (b). The green dotted line denotes the outer boundary of the true cavity. The yellow dotted line depicts the approximate outer boundary of the flux rope.

We have also found that the cavity exhibited non-self-similar expansion in the lower corona, below 2.2 ± 0.2 R_S and a strong deflection at 1.3 R_S. Furthermore, by comparing the decay-index profiles of the cavity system during the different stages of its evolution from quiescent to pre-eruptive phases, we have found that the eruption of the CME is triggered when the decay index reaches a critical value required for the onset of torus instability. Therefore, we conclude that the decay-index value at the cavity centroid height can be used as a good indicator to predict the cavity eruption in the form of CMEs. https://doi.org/10.3847/1538-4357/ab11c5

Interplanetary Coronal Mass Ejections (ICMEs) during Solar Cycles 23 and 24: Sun–Earth propagation characteristics and consequences at the near-Earth region

(*M. Syed Ibrahim, Bhuwan Joshi, K.-S. Cho, R.-S. Kim and Y.-J. Moon*)

Syed Ibrahim

Coronal mass ejections (CMEs) and associated eruptive flares are the most violent manifestations of the active Sun. While a flare is attributed to the sudden and impulsive release of a huge amount of energy (≈10^{27}–10^{32} ergs on the time scales of a few to several tens of minutes) from a localized region of the solar atmosphere, CMEs primarily represent the eruption of a large amount of plasma from the Sun (≈10^{14}–10^{16} g with speeds ranging from <100 to 2500 km/s). This work encompasses the ICME activity that occurred during Solar Cycles 23 and 24 (1996 – 2017) while presenting an overall picture of ICME events during the complete Solar Cycle 24 for the first time. The importance of this study further lies in comparing two subsets of ICMEs, *i.e.* magnetic clouds (MCs) and ejecta (EJ), to explore how the observed structures of ICMEs at 1 AU could be associated with the properties of CMEs during their launch at the Sun. We found that, although a significant reduction in the number of ICME events in Solar Cycle 24 compared to the previous cycle, the fraction of MCs was much higher during Cycle 24 than Cycle 23 (60% *versus* 41%, Figure 1). A combination of multiple parameters affect the evolution of ICMEs, such as CME properties at the near-Sun region (*e.g.* speed, acceleration, and structure) along with changes in the background solar wind. The CME propagation from the Sun to the near-Earth environment shows an overall positive as well as negative acceleration (*i.e.* deceleration), although the acceleration is limited to only low-speed CMEs that are launched with speeds comparable with or less than that of the mean solar wind speed, i.e. about 400 – 450 km/s (Figure 2). Within a given cycle, the similarities of MC and EJ profiles with respect to the CME–ICME speed relation as well as interplanetary acceleration support the hypothesis that all CMEs have a flux rope structure and that the trajectory of the CMEs essentially determines the observed ICME structure at 1 AU.

https://doi.org/10.1007/s11207-019-1443-5

Figure 1: (a) Histograms showing the annual occurrence of ICMEs and, (b) Two types of ICMEs, *i.e.* MCs (*white bar*) and EJs (*black bar*), during Solar Cycles 23 and 24.

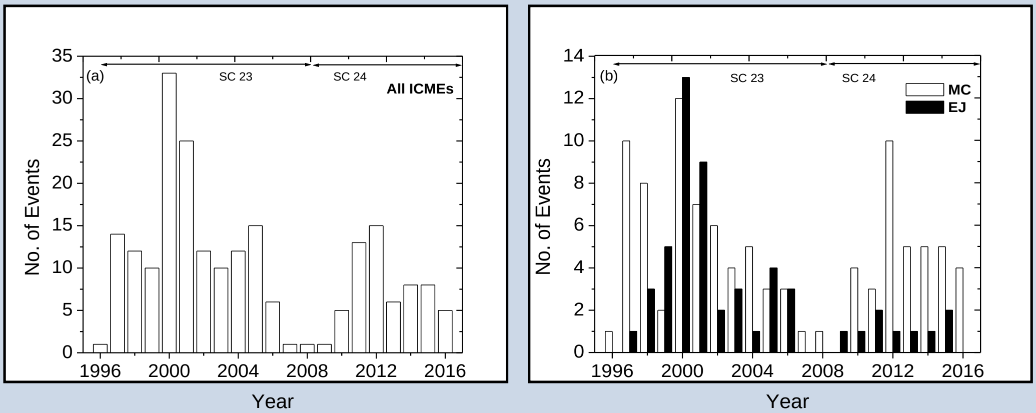
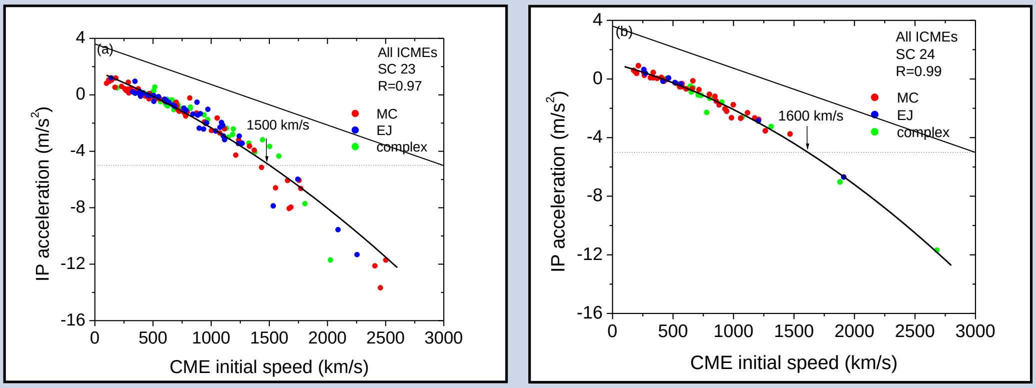
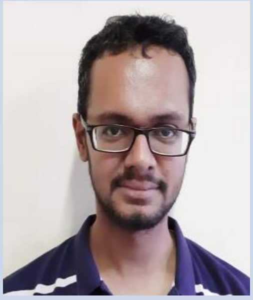


Figure 2. Relation between the initial CME speeds and the interplanetary (IP) accelerations for all ICMEs during (a) cycle 23 and (b) cycle 24. We have drawn a dotted horizontal line at an arbitrary acceleration value of −5 m s^{-2} to compare the acceleration profiles during the two cycles.



Ultracold mercury–alkali-metal molecules for electron electric dipole moment searches

(A. Sunaga, V. S. Prasannaa, M. Abe, M. Hada, and B. P. Das)



Srinivasa Prasannaa V

The electric dipole moment of the electron (eEDM) is a measure of the roundness of an electron's charge distribution. This intrinsic property of an electron is special, as it arises due to simultaneous violation of parity and time reversal symmetries. This would mean that for this property to exist, the laws of physics should no longer be the same between the familiar world around us and one that is a 'mirror' as well as a time-reversed version of ours. The property has not been detected yet; measurements from high-precision molecular experiments, in combination with relativistic many-body theory, provide upper bounds on it. These bounds aid in constraining several theories beyond the well-established Standard Model of elementary particles, and also provide insights into why our universe is dominated by matter, and not anti-matter. In our work, we propose mercury alkalis as promising molecular candidates for future eEDM search experiments. Using a relativistic quantum many-electron theory, we show that it possesses attractive theoretical features for an eEDM experiment. We also explore its experimental feasibility of producing and trapping ultra-cold samples in large quantities for sustained periods of time. We estimate that these features are attractive enough to beat the current record for the best bound that is set by thorium monoxide.

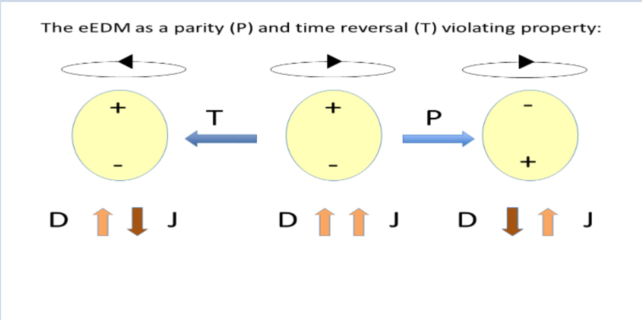


Figure Caption: A pictorial representation of eEDM violating parity (P) and time-reversal (T) symmetries. The action of P on the electron (in the centre) flips D, while T flips J. In either of the cases, if the laws of physics are to be the same, one can see that eEDM is zero.

https://doi.org/10.1103/PhysRevA.99.040501

Events & Activities

Valediction Ceremony of UN Courses

The 11th Post-Graduate Diploma Courses on (i) Satellite Meteorology and Global Climate (SATMET-11) conducted by Space Applications Centre (SAC) and(ii) Space and Atmospheric Science (SAS-11) conducted by Physical Research Laboratory (PRL), under the aegis of the UN-affiliated Centre for Space Science and Technology Education in Asia and the Pacific (CSSTEAP), were successfully completed on April 30, 2019. A Joint Valedictory Function of the two courses was held on Monday, April 29, 2019, at Bopal Campus, SAC. Shri A. S. Kiran Kumar (Prof. Vikram Sarabhai Professor, ISRO HQ), the Chief Guest, presented the certificates to the participants. Dr. Senthil Kumar (Director, CSSTEAP), Dr. Anil Bhardwaj (Director, PRL), Shri D K Das (Director, SAC), and senior members from SAC and PRL graced the function.

YUva Vigyani KAryakaram (YUVIKA) Visit in PRL

Thirty-three participants of ISRO's special programme YUva Vigyani KAryakaram (YUVIKA) for the school students across the country visited PRL on 14 May 2019. This programme is aimed at imparting basic knowledge to the young students on space technology, space science and space applications in order to arouse their interest in emerging areas of Space activities. The visit included lectures about PRL as an institute and the diverse set of activities, talks, followed by interaction, on Telescopes, Space and Atmospheric Sciences and Planetary science by PRL faculty members and the Director. Students visited four laboratories in the PRL main campus and four laboratories at the Thaltej campus. There was an active and enthusiastic participation and students were very thrilled, which was clearly evident from their questions during interactions. The visit, coordinated by the Outreach team of PRL, saw an active participation and support of PRL colleagues from academic, scientific and technical as well as administration fraternity.

Outreach

Visit of meritorious students of Aryabhat Foundation, Bhopal to USO

USO-PRL hosted the annual visit of meritorious students of the Aryabhat foundation on 21st May 2019. A 3-member, school student team visited USO with their mentor. They were first given a short introduction about the Observatory and its existing facilities. Later, they were shown live, high-resolution, small-field images of the Sun from the 0.5m MAST as well as full-disk solar images from the 15 cm SPAR telescope. They also visited the GONG facility and e-Callisto located in the office premises. The enthusiastic student team also gave a short presentation on **"Life: Earth and beyond"** in the USO seminar hall which generated a lot of interest in the audience. The presentation was followed by a short Q &A session. The students enjoyed their visit and interacted with the scientists at USO with great enthusiasm. The Aryabhat Foundation of Madhya Pradesh is focussed on the popularization of Astronomy among the highly motivated, senior school students of M.P.

PRL and me!

April, 2019 came and brought with it, mixed feelings. I had started working at a very young age, and was looking forward to the break that retirement brings with it. But then, I had never ever 'not been working'. Towards the last week, I walked around with a heavy heart and a lump in my throat as the day of my exit from PRL came nearer. On 30th April, as I parked in my usual spot, I took a minute to breathe deep, look around and march towards the end of my stint at PRL.

My association with PRL as an employee goes back to 1981, when, perhaps many of you were not even born. Those days were different. A memory that stands out, when I look back to the 1980's, is that there used to be movie screenings held at the library lawns almost every weekend. The screenings usually turned into impromptu picnics and a bonhomie developed that binds me, even now to colleagues that went on to become friends and family.
I was initially placed with the erstwhile Geocosmophysics area. Working with the area chairs and the group faculty members was very satisfying and memorable. Teaching and guidance from Professors. K. Gopalan, T.R. Venkatesan, N. Bhandari, A.K. Singhvi, et al. enriched and instilled great confidence in my young mind. When I was moved to Chemistry Lab after the periodical change of Area Chair, I had great mentors in Professors S.Krishnaswami, BLK Somayajulu and M.M. Sarin who were not just 'taskmasters' that demanded excellence but also folks who made the workplace fun, with birthday parties and family get togethers. I owe a lot to all the members of this group for enriching my learning and also because I made friends for a life time, here.

After almost two decades of working in a scientific area, I was transferred to Administration. It was a challenge and it took me some time to adjust to the new work and changes in responsibilities. I worked to the best of my abilities and I am glad that my work was appreciated. Subsequently I was moved to work in Registrar's office and later to work with the Director.

During my tenure at Director's office, I had the privilege to work with four different Directors. I sincerely express my appreciation and respect for the support and encouragement provided to me and the deepest gratitude for believing in me. I will always appreciate their unparalleled commitment to PRL. Being in the highest office of PRL, I had the opportunity to interact with the various area chairs, committee members, technical and administrative personnel and I am grateful to everyone for their co-operation and guidance. My respect and reverence goes to the retired senior faculty members who were dependable, supportive and encouraging. My role also involved interactions with Students and PDFs, especially since I was dealing with foreign deputation. I also played a bit of a role in the workshops organised by the students. I found most of them very extremely focused and ambitious, a trait, I am sure, will take them to places. I also owe special thanks to the dear members of Director's office and also my colleagues at the 8th floor, who made sure that even in the midst of the busiest, most difficult days, we found little things to laugh and smile about.

I was part of various committees during my tenure and have worked committedly for each agenda that these committees had. However, closest to my heart is the Internal Complaints Committee, that grew, in scope and work as I did. I will cherish the memories we made for years to come.

My tribute to PRL is incomplete without the mention of my group of friends who have provided unconditional support and made all the celebrations fun and helped me to be myself. I look back with immense satisfaction and a degree of pride at the 38+ years that I have spent at PRL. To each of you who read this, I wish that when you depart from PRL, you are able to look at the Institute and feel the same sense of gratitude, affection, belonging, passion and fulfilment that I feel for it.

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Sr. Administrative Officer (Retd.)
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