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From UCLA to CBPF and the University of Virginia: A scientific journey of two friends, Ronald Cintra Shellard and P. Q. Hung

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In this commemorative article in memory of Ronald Cintra Shellard, I will retrace the scientific journey that Ronald and I have travelled since our graduate student days at UCLA to the last time we met at the International Centre for Interdisciplinary Science and Education (ICISE) in Quy Nhon, Vietnam, on the occasion of a particle physics workshop and the signing of a Memorandum of Understanding (MOU) between CBPF and ICISE.

INTRODUCTION

It was with a shock and profound sadness that I learned of the death of my dear friend, Ronald Cintra Shellard, on December 7, 2021. It was a shock because Ronald had been not only a close friend since the days we were fellow graduate students at UCLA but also a role model for the type of physicist I aspired to become – because he had such a breadth of knowledge for a graduate student! I learned a lot from him during those graduate student days. Somehow, after graduation in 1978, we did not have the chance to cross paths with each other until a few years ago.
We first met at UCLA in 1974 and we last met in Quy Nhon, Vietnam in 2019. I will describe, below, our scientific (and cultural) journey and our unfulfilled project of a scientific exchange between Brazil and Vietnam through CBPF and ICISE.

THE UCLA DAYS

I arrived at UCLA in the Fall of 1972 to begin my graduate studies in Physics. My initial desire was to go into Plasma Physics since UCLA has a very strong group in this field. Although Plasma Physics is a very interesting field, I was soon attracted to Elementary Particle Physics and decided to pursue a career in this area, so I choose if for my PhD. What a lucky choice I have made, since this was where I met Ron a couple of years down the line.

For UCLA Physics graduate students, the first two years are divided as such: core courses in the first year, and advanced courses in the second year (at least in those days). More specialized courses, such as the seminar ones, were normally taken in the third year and after. Ron transferred to UCLA from UCSB in the Fall of my third year. We both took a seminar course on Special Topics in Elementary Particle Physics taught by Professor Nina Byers.

During that Fall semester, a Particle Physics revolution occurred on November 11, 1974, and was dubbed the November Revolution: the discovery of a new meson with mass $\approx$ 3.1 GeV and named J/Ψ. It soon became clear that J/Ψ was a bound state of a brand new quark, the charm quark c, with its anti-charm quark $\bar{c}$. By November 1974, only three quarks were known: u, d and s. Ordinary hadrons (protons, neutrons, pi mesons, etc.) are bound states of these three quarks. They were classified under a symmetry group $SU(3)$. With an additional quark c, the (badly broken due to a large disparity in masses) symmetry group would become $SU(4)$. Since not many students in the class knew much about group theory, Ron volunteered to give us a lecture on hadrons formed from these four quarks based on the symmetry group $SU(4)$. It was a beautiful lecture and we learned a lot. It is too bad that I no longer possess Ron's lecture notes, but I can still vividly remember, after 48 years, the 3-dimensional drawing of charmed hadrons where the vertical axis represents the charm quantum numbers (the other two quantum numbers: isospin and strangeness are on a plane that contains non-charmed hadrons). Ron's lectures prepared us well for a deluge of papers that came out after the November revolution.

A side note: In the Spring of 1974, I took a quantum field theory course from Nobel Prize winner Julian Schwinger. One day, Professor Schwinger walked into the class and proceeded to derive the formula for the famous ratio $R = \sigma(e^+e^- \to hadrons)/\sigma(e^+e^- \to \mu^+\mu^-)$, which, according to the prevalent view where mesons are quark-antiquark bound states, the parton picture should be $R = 3\ Q$, where Q_i is the electric charge of the ith quark (i = 2/3, −1/3, −1/3, 2/3 in unit of e for u, d, s, c respectively). This R-ratio is a function of the center-of-mass energy of the electron-positron collider. For energies greater than the mass threshold of the heaviest meson, R is a constant and is given by the aforementioned formula. What Professor Schwinger showed in the Spring of 1974 was that, experimentally, *R increased with energy*, in contradiction with the expectation that it

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should be a *constant* if one had only 3 quarks. According to Professor Schwinger, this experimental result was "the nail in the coffin for the parton model"! However, it turned out that this rise in R was due to the fact that the collider was *approaching* the threshold of the J/Ψ meson and R should rise from R (3 quarks) to R (4 quarks). We were happy that the parton model *actually worked* and that the charmed mesons were detected as we have seen in Ron's lectures.

I became a friend of Ron's and another student from Chile, Luis Urrutia, who is now a professor at UNAM in Mexico City. It was through Ron that I discovered the magic of Tom Jobim's music and Bossa Nova. Ron played *Desafinado* for me through the wonderful voice of João Gilberto. It was a revelation for me, in particular with the strange guitar chords. (Growing up in the Sixties, I was more attuned to Rock music, especially the music of the Beatles.) Ron, Luis and I spent several evenings listening to Brazilian music. One of my wishes then and now was to visit Brazil if I had a chance.

Ron and I took slightly different paths toward our PhD: a theoretical one on dynamical symmetry breaking (DSB) for Ron under the supervision of Professor John Cornwall, and a more phenomenological one on weak interactions for me under the guidance of Professor J.J. Sakurai. Although Ron's and my PhD topics were quite different, little did I know that I would be interested in DSB several years later in my attempts to understand the nature of the symmetry breaking of the Standard Model (SM) of elementary particles, whether it is accomplished by a composite Higgs particle through DSB or by an elementary Higgs field.

Last but not least, two pictures of us during those UCLA days are shown below

Figure 1: Ronald C. Shellard and P.Q. Hung.

THE POST-UCLA DAYS

After Ron and I graduated in 1978, we parted ways. Ron moved back to Brazil, first at IFT in Sao Paulo (1978-1983)m second at the Pontifícia Universidade Católica in Rio de Janeiro (1983-1994), and finally at CBPF in Rio de Janeiro (1994-2021). For myself, I went for a postdoc, first at Fermilab (1978-1980), next at Lawrence Berkeley Laboratory (LBL), University of California at Berkeley (1980-1982), and last as a Faculty member at the University of Virginia, Charlottesville, Virginia (1982-present).

Since we lost track of each other after our graduation from UCLA, I can only describe Ron's achievements based on his public records.

After continuing as a theorist working on interesting topics such as DSB and theoretical aspects of $\lambda\varphi^4$ theories, Ron switched to experimental physics by joining the DELPHI collaboration at CERN. This was remarkable in the sense that there were very few physicists who were able to make the switch and to remain successful. Enrico Fermi was a shining example of such a switch, despite the fact that he was doing both. Another theorist – once my collaborator – was James Bjorken who, at one point, devoted many years of his life to an experiment at Fermilab searching for a hypothetical particle named axion. Ron's participation in the DELPHI collaboration has, in some sense, opened the gate for Brazil to later participate in various other CERN experiments, leading ultimately to the full acceptance of Brazil as an Associate Member of CERN on March 3, 2022. It was so sad that Ron was not there to participate in that momentous event.

The particle collider that existed before the present Large Hadron Collider (LHC) was an electron-positron collider named LEP which had four large detectors, one of which was DELPHI, which operated from 1989 until 2000. Ron joined the DELPHI collaboration since the beginning of its operation. The many interesting aspects of Particle Physics it was designed to study included the searches for the Higgs boson H and for supersymmetric particles. The maximum center-of-mass (CM) energy of LEP was 209 GeV and the search for the Standard Model (SM) Higgs boson was through the process $e^+ + e^- \to Z + H$. For LEP to be able to discover the SM Higgs boson H and with the Z-boson mass being $M_Z \approx 91$ GeV, the constraint on the H-mass is $M_H < 118$ GeV. Unfortunately, the Higgs was discovered in July 2012 at the LHC, with a mass larger than the aforementioned bound by 7 GeV, namely $M_H \approx 125$ GeV. Had the CM energy of LEP been at least 7 GeV larger, DELPHI might have had the chance of making a fundamental discovery, that of the Higgs boson! It was unfortunate that Ron missed out on this... but this is life. Suffices to say that Ron has participated in a very important experiment. At this point, Ron was getting ready to change direction, that of Astroparticle Physics by joining the Pierre Auger Observatory, an international observatory built in Malargüe, Mendoza, Argentina, with the aim of looking for ultra-high energy cosmic rays with energies exceeding 10^{18} eV and checking whether they come from within the Milky Way or beyond.

Before joining the Pierre Auger collaboration, Ron participated in a White Paper outlining the various ways one can measure using nuclear reactors the very important mixing angle θ_{13} in the neutrino sector whose non-vanishing value would signal the violation of the discrete symmetry CP (charge conjugation-parity) in the leptonic sector. This angle was finally measured several years later at Daya Bay, a nuclear reactor in China.

The Pierre Auger Observatory started taking data since 2005, one year after Ron joined the collaboration. It has been operating magnificently well since 2005 and the data from 2017 showed that ultra-high energy cosmic rays exceeding 40 EeV (1 EeV= 10^{18} eV) are anisotropic, pointing most significantly towards Centaurus A and the most Active Galactic Nuclei (AGN). These are very interesting results, and I believe the contribution of the Brazilian group under

Ron's leadership is very important.

Ron's experience with the Pierre Auger Observatory has led to many initiatives including his important role in the SWGO (Southern Wide-Field Gamma-Ray Observatory) project where he was a member of the Steering Committee representing Brazil. It goes without saying that Ron has played an extremely important role in the development of the field of Astroparticle Physics in Brazil, and would continue to do so had he been still around with us. There are many other contributions he made to Brazilian Science and Education, which will be discussed by other contributors to this special issue.

As for my own trajectory since graduation in 1978, I will be very brief since this article is about Ron and not about me. Nonetheless, I shall describe it for the simple reason that what I was working on ultimately led us to organize a conference in Vietnam titled "New Physics with Exotic and Long-Lived Particles: A Joint ICISE-CBPF Workshop, July 1-6, 2019", which was also the occasion to sign an MOU between CBPF and ICISE.

The topic of my PhD dissertation was about the structure of Weak Neutral Currents, which were discovered experimentally in 1973. This was carried out under the guidance of Professor JJ Sakurai. Our model-independent analysis agreed with the prevalent model of that time, namely the Weinberg-Salam model, when new data from the SLAC experiment were taken into account. Sakurai and I – and, independently, Bjorken – built a model that satisfied NC data, but was not necessarily the W-S model. After moving to Fermilab as a postdoc, I became convinced of the correctness of the Glashow-Weinberg-Salam model (now called the SM). I started to look at constraints on the SM, in particular the interplay between the Higgs boson mass and that of a heavy fermion: for a given Higgs mass, the heavy fermion mass cannot be too large; otherwise, the vacuum would become unstable. Thirty-eight years later, after the discovery of the Higgs boson and with the mass of the heaviest quark presently known, namely the top quark with a mass $m_t \approx 173$ GeV, we learned that the SM is metastable if we assume that there is nothing else. Before launching into a full study of neutrino physics, I have also worked on models of Dark Energy and Dark Matter. I have always been fascinated with neutrinos, in particular with the question of why they are so light compared with all other elementary particles. Within the SM where right-handed neutrinos are absent, neutrinos are massless. Adding right-handed neutrinos can generate very light (almost left-handed) neutrinos through a very popular mechanism: the seesaw mechanism. Whereas the most common approach was to assume that right-handed neutrinos do not interact with other particles through the SM gauge bosons, I took a different route in which they do have interactions, and that has led to the concept of mirror fermions. These mirror fermions turn out to be long-lived (a subject of our joint workshop which I will describe below). Furthermore, right-handed neutrinos in this model have masses a few times larger than the W boson mass (hence the name "electroweak right-handed neutrinos") and can be searched for at the LHC. Last but not least, in order for right-handed neutrinos to have such masses, the Higgs sector has to be enlarged so as to include two triplet Higgses, one of which gives rise to the existence of an electroweak magnetic monopole. Such a monopole is being searched for at dedicated experiments such as the CERN MoEDAL experiment.

Here, I followed Ron's footsteps by joining the MoEDAL collaboration. I was longing to learn more from Ron about various aspects of Astroparticle Physics and also about the organization skills that have proved to be crucial to the development of science in Brazil, as I have learned from him about $SU(4)$ when we were graduate students.

THE CBPF-ICISE COLLABORATION

Four years ago, Ron and I discussed the possibility of starting a research collaboration between us and, in particular, between Brazil and Vietnam through an MOU between CBPF and ICISE. We assembled an Organizing Committee and came up with the title and a list of topics and speakers, as can be seen in the following website:
https://indico.cern.ch/event/817777/

Our MOU signing ceremony was held on the last day of the conference. The main impetus of this MOU was to have scientific exchange between Vietnam and Brazil, not only in physics but also in domains such as agriculture where Brazil's expertise can greatly help Vietnam in the coming years when climate change effects can be devastating for countries with long coast lines – such as Vietnam!

Below are a few pictures of the MOU signing ceremony.

Figure 2: MOU signing ceremony.

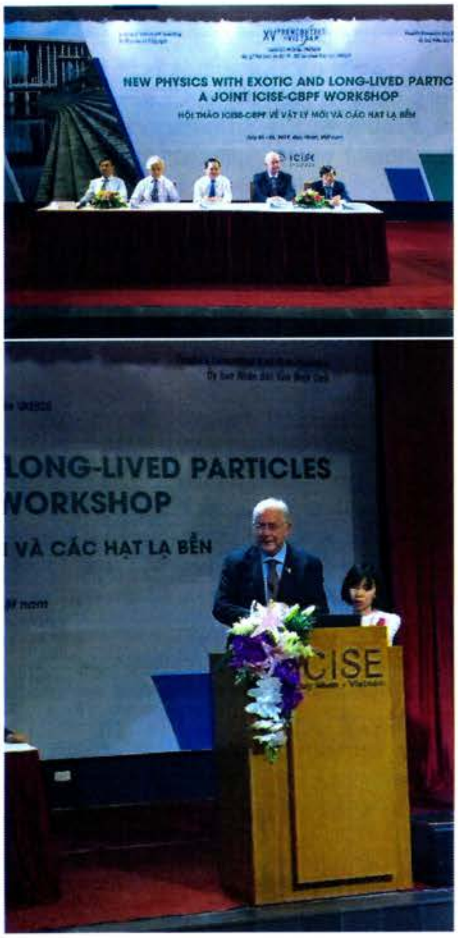

Figure 3: MOU signing ceremony.

Figure 4: MOU signing ceremony.

During the pandemic, Ron and I managed to keep in touch through Skype and Zoom. We had many fun conversations and talked about what we would do once the pandemic was "over". Unfortunately... In memory of my friend Ronald Cintra Shellard, I hope that this collaboration will continue as Ron would have wished it to be.

I would like to offer my condolences to Maria Elisa Shellard. We both miss Ron and I hope to finally meet her in person one of these days.

So long Ron...

I would like to thank Professor Márcio Portes de Albuquerque and Professor Ildeu de Castro Moreira for the invitation to contribute to this Special Edition. This has opened a floodgate of memories which had been kept private for so many years.