ARTICLES ON NUCLEAR-, PARTICLE- AND ASTRO- PHYSICS

NOBEL LAUREATES SHOW US THE WAY[1]

The recent award of the Nobel Prize for Physics to three astrophysicists witnesses the dynamism of the field. It brings to seventeen the number of Nobel laureates in astrophysics since 1950, half of whom are in the past ten years. To the extent that Nobel Prizes are a good indicator of the trends in contemporary physics, it gives an opportunity to underline the importance of promoting training and research in astrophysics in Vietnam. Moreover, it illustrates features of contemporary science which may be insufficiently developed in the country and which deserve some comments: I am particularly thinking of the balance between theory and experiment and of the importance of team work.

If traditional astronomy is probably the oldest among sciences, modern astrophysics is one of the youngest. Less than a century ago, Einstein thought that the Universe was static! Fifteen years ago, most astronomers had strong doubts about the existence of black holes; we have good reasons today to think that each spiral galaxy has one in its centre and we have observed in great detail and at all wave lengths Sagittarius A*, the black hole in the centre of the Milky Way, 24'000 light years away from us, some three million solar masses. Pulsars, quasars, Super Nova Remnants, Active Galactic Nuclei, White Dwarfs, Red Giants, Gamma Ray Bursts and other members of the astrophysics zoo were unheard of a few decades ago. The cosmic microwave background was discovered less than 50 years ago and its granular structure, an essential element in our understanding of the evolution of the Universe, less than 20 years ago.

The most puzzling questions of modern physics are related to astrophysics: the mismatch between what we know of the energy density in the Universe and what we infer from its expansion (dark energy); the mismatch between what we know of gravity and the movement of stars in galaxies and of galaxies in clusters (dark matter); the mechanism of the exponential expansion which took place just after the Big Bang (inflation) and its relation with Grand Unification, spontaneous symmetry breaking and the generation of masses. Indeed, astrophysics is an essential input to modern attempts to find a sensible substitute to general relativity and quantum physics in the region of the Planck mass where they are incompatible (superstring theories).

As is often the case for young sciences, astrophysics borrows from nearly all other branches of physics: particle physics for the first fractions of a second in the life of the Universe; nuclear physics for the primordial nucleosynthesis, some 3 mn after the Big Bang, and for the physics of stars from birth to death; plasma physics for stellar atmospheres, stellar winds and interstellar matter; molecular physics for the study of cold matter; atomic physics for spectroscopy; condensed matter physics for neutron stars, planets, dust, etc… gravity for stellar dynamics and cosmology and even biology when trying to understand where life on Earth came from. It offers a unique laboratory to study forms of matter in so extreme conditions that they are completely inaccessible to terrestrial laboratories: plasmas, whether in interstellar matter or in stars, white dwarfs, with a degenerate electron gas, neutron stars… not to mention black holes.

Such a diversity is also present in the instruments and methods used in the observations that we are making of the Universe, covering not only the whole electromagnetic spectrum (radio, microwaves, infrared, visible, ultraviolet, X-rays, γ rays) but also cosmic rays (nuclei and neutrinos). The sudden accessibility of space, in the sixties, played an essential role in the blossoming of modern astrophysics and made it possible to explore the Universe at frequencies absorbed by the Earth atmosphere and previously out of reach of terrestrial exploration. At the same time, ground observatories make extensive use of very sophisticated techniques such as adaptative optics and radio interferometry.

Such a fascinating field of science, developing so rapidly, should not be absent from the Vietnamese scientific landscape. While only rich countries, or more often collaborations of several countries, can

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afford to launch satellites or build gigantic ground observatories, the data that they record are available to anyone who can show that he, or she, can make good use of them. As I often say, we are all invited to the banquet, the sky belongs to all of us and we are all made of the same stardust. It is time to make an effort to develop modern astrophysics in the country. There exists already enough competence at home to provide the seed for such an effort. Several Vietnamese astronomers of international stature who are working abroad could support it. Before the end of the present decade, Vietnam should have an Astrophysics Institute as one of its centres of excellence in modern science.

Scanning through the list of Nobel Prizes awarded for astrophysics suggests another comment: of the seventeen laureates, only two, Bethe and Chandrasekhar, are theorists (three if one includes Fowler). No surprise, one might say, for such a young field of science. If I mention it, it is because of my experience with Vietnamese universities. I remember a student who, in my opinion, did not deserve a good mark. His professor told me that I could not give him less than 9 because he was from the theory class and students from the theory class never get less than 9. After lengthy arguments, I had to give in. Finally, to my surprise, the 9, that I had reluctantly agreed to, had become a 10…When Vietnamese physics students graduate, they are convinced, in their vast majority, that if they are good students and wish to be scientists, they should become theorists; if they are mediocre students and still wish to be scientists, they should become experimenters. Clearly, they do not invent such monstrosity, they must have been told so, explicitly or implicitly; they must have got the impression that theory is the noble face of science, experiment the dirty part. But who thinks so has not understood anything to science: science is made of a dialogue between the two, they feed each other. Experimenters need the light of theory to show them which way to go, what to explore and why; theorists need the data of experiments and observations in order to give of it as simple an interpretation as possible. In a letter to Bates, who had just come back from his Amazonian expedition, the 51 year old Darwin wrote *"a good observer really means a good theorist"*. Indeed, Darwin was both. This is what we must teach students: if they wish to become theorists, they better learn about observations and experiments; if they wish to become experimenters, they better learn about theory. Never should one give them the impression that there is a hierarchy between the fields of science: there is beauty in all of them as long as they are explored with rigour and ingenuity.

The last point I wish to make is about team work. All of the eight astrophysics laureates of the past ten years are working in teams, often very large; their papers are co-signed by some thirty authors on average. Their names are attached to famous research collaborations such as Homestake Mine, COBE, Uhuru, Kamiokande, SN Cosmology Project and High-z SN Search. This is the way modern astrophysics progresses these days; the same trend is to be found in many other fields of physics, such as particle and nuclear physics. Whether one likes it or not, it is the only way, in such fields, to have a chance to progress at the forefront of contemporary research. It is neither good nor bad, one just has to get used to it and adapt our research style to reality. Vietnam has much to do in this domain. For example, in the assessment of physicists and research projects, team work is not recognized as it should be and physicists publishing in collaboration with others are depreciated. You better publish a bad paper alone than a good paper together with colleagues. Worse, the need to build up teams in modern physics is not appreciated: when a Vietnamese comes back home with a PhD awarded abroad, he should be encouraged to build a new research team (and be given the necessary support) if he is excellent, or to join an existing team if he is simply good. This implies choices in the fields of physics that the country wishes to support; it implies a clear scientific policy. What happens instead, most of the time, is that he is left alone and continues to work in his corner, alone, on the same field as that of his PhD, simply maintaining contact with his PhD team abroad. This is not the way to develop modern scientific research in the country. The *Eureka!* of Archimedes, jumping naked out of his tub, is out of fashion today.

MODERN PHYSICS IN VIETNAM: WHICH PRIORITIES?

The XXth century has seen the successive growth of three new branches of modern physics that are still today at the frontier of fundamental research: nuclear physics, particle physics and astrophysics.

At the same time, the physics of complex systems made spectacular progress in the fields of condensed matter physics and biophysics. In the present note, I shall deal with the first group exclusively.

Nuclear physics has dominated the scene for the first half of the century, both for the importance of its applications and as the only tool to study the strong interaction. Originally using radioactive sources to produce its projectiles, it was strongly boosted in the second third of the century by the availability of particle accelerators. Soon, however, the energy increase that was made possible with synchrotrons brought particle physics, which had been using cosmic rays as probes until then, to the forefront of modern physics. In the seventies, particle physicists discovered QCD, which seemed to deprive nuclear physics of one its main *raison d'être*. But very soon thereafter, nuclear physics experienced a spectacular *renaissance* with the availability of radioactive beams that opened a new window on the physics of nuclei far from stability. At the same time, it was realized that QCD could be handled easily in the perturbative regime exclusively: its study in the confined sector, which remains today at the forefront of theoretical research, brings up many unanswered questions. Heavy ion physics, with high energy colliders at Brookhaven (RHIC) and at CERN (LHC/ALICE) gathered physicists from both the particle physics and nuclear physics community to study nuclear matter in extreme conditions, which were once realized very shortly after the Big Bang and are still present in some very compact stars (neutron stars).

Particle physics made a gigantic leap forward in the early eighties with the advent of the so-called Standard Model that describes the world as the result of space-time symmetries – possibly including Supersymmetry – exchange symmetries having a group structure – $SU(3)_{colour} \times SU(2)_{left} \times U(1)$ – and gauge invariance. Since then, none of its most burning questions has found an answer. They cover the Higgs sector – the regime of spontaneous symmetry breaking and the mechanism of mass generation – and the role possibly played by Supersymmetry, both of which are expected to find an answer with LHC, the new CERN proton Collider that came into operation one year ago. But they also include questions in the highest energy sector, which seems out of reach of any terrestrial conceivable accelerator: Grand Unification, quark-lepton connection, triplication of fermion families and incompatibility of gravity and quantum physics. For now thirty years, most of theoretical research has concentrated on the Planck sector using superstrings as basic elements, where all the latter questions are expected to find an answer.

Astrophysics bloomed in the late XXth century, with the availability of space astronomy opening a new window on the gamma-ray, X-ray, UV, infrared and microwave Universe, which had not been observed earlier. At the same time, spectacular technical progress was accomplished in ground astronomy, both optical and radio, with tools such as the Very Large Array in the US or the European Very Large Telescope in Chile becoming available. At the very end of the century, one had been able to draw the picture of a 14 billion year old flat Universe, obeying the Robertson-Walker metric, and one had understood most of the mechanisms that govern the birth, life and death of stars. However, the so-called "Concordance Model" that had emerged is bringing up many unanswered questions: nearly a quarter of the mass of the Universe is made of cold dark matter having only gravity interactions, of an unknown nature, and most of the remaining three quarters, called dark energy, can be described by a cosmological constant but its physics is a complete mystery. Moreover, strong indications suggest the occurrence of an inflatory phase just after the Big Bang, but no realistic model has yet been conceived. Astrophysics is progressing very fast today, with the exploration of the high redshift early Universe at the era of reionization and the study of violent events such as Gamma Ray Bursts and Active Galactic Nuclei.

The interrelation between the three fields, nuclear-, particle- and astro-physics, is strong and deep. Indeed much of their research community has migrated from one to the other over the years and several of the older physicists have been active in the three domains. Understanding the evolution of stars, from birth to death, or the genesis of the first nuclei three minutes after the Big Bang, requires a deep knowledge of nuclear physics; understanding inflation requires a deep knowledge of particle physics; shedding light on the Planck scale region, at the border between gravitation and quantum physics, requires a deep knowledge of astrophysics and particle physics.

A common feature of the three fields is their being part of what is commonly called "Big Science". It means that progress requires the use of large instruments operated by large collaborations. This is the

price to pay if one wishes to work at the frontier of knowledge. Today, the LHC (Switzerland) dominates the scene in particle physics; there is more diversity in the nuclear physics landscape with centres such as RIKEN (Japan), GSI (Germany), GANIL (France), etc… In astrophysics many ground and space instruments are operated by NASA (US) or by ESO (Europe) but there also exist a large number of optical and radio telescopes, including radio interferometers, which are at the top of the state of the art. For Vietnam to take part in such collaborations, it is necessary to have a team at home with a sufficient critical mass to make significant contributions. This has been largely neglected in the past and can no longer be in the future. This is particularly true in particle physics where no support has ever been given to create a Vietnamese particle physics group in spite of the very high concentration of the world effort on the LHC and the very competitive community that it implies. When such a team exists, however, Vietnam can have easy access to nearly all large instruments around the world. While it would make no sense for Vietnam to compete with other more developed countries on the construction of such large instruments, the availability at home of smaller instruments allowing for the training of students, such as the Tandem Accelerator at HUS or the Radio Telescope at VATLY, are very important assets.

It is clear that Vietnam has a stronger need for applied sciences than for fundamental sciences. Although it is tempting to underline possible applications of particle physics and astrophysics in order to plead their case, it must be clear that the main motivation to develop such fields of science in Vietnam is the belief that a developed country must have some research activity at the frontier of knowledge; it is an argument of excellence, the determination to start research in domains which had been inaccessible to the country during the difficult decades that preceded Doi Moi, the conviction, unanimously shared by all academics around the world, that good universities must host and foster forefront research. It is true and recognized that such fields are excellent training grounds, it is also true that Internet was invented at CERN, that satellite and space technology go hand in hand with fundamental astrophysics, etc. but this should not be the main argument to plead their case. The mistake of overselling fundamental research for its applications has been made in the US when promoting the SSC twenty years ago and has led to disaster. Even for nuclear physics, the basis of nuclear applications in domains that are essential for tomorrow's Vietnam, such as electricity generation and medical or industrial applications, fundamental research should not be mixed up with the training of the applied physicists, engineers and technicians that such applications require.

A last comment concerns theory. It must be clear that theory and experiment – or observation – go hand in hand and feed each other, that there is no hierarchy between them and that a good physicist must be conversant in both. This is not always sufficiently understood in Vietnam. A successful physics institute must include talents in both sectors.

It seems that it is now time to consider the establishment of a research centre in Vietnam having the ambition to promote fundamental research in the above fields of physics. Nuclear physics, with existing Vietnamese research teams active abroad, with a new Tandem accelerator available at HUS and with the presence of a nuclear theorist at INST having international reputation in modern nuclear physics, seems a very good case. The same argument applies to astrophysics, particularly radio astronomy, with the VATLY radio telescope for the training of students, with researchers at IOP/Hanoi, HCMC International University and INST/VATLY working in collaboration with prestigious foreign teams on major instruments such as the VLA and having an important Viet Kieu representation of international reputation. The case of particle physics is less clear: until recently the main effort was on LHCb at the HUS, of excellent quality but with insufficient support to create a team having the critical mass. Recent contacts with the ATLAS collaboration may change the scene by joining efforts on a single experiment. However, the time scale implied in the construction of new colliders extends over many decades, which is not in favour of Vietnam where young physicists must be turned into active researchers as soon as possible. It is an important argument that needs to be taken in due consideration. For example, in astrophysics, it leads to prefer radio astronomy, which is in rapid expansion with high redshift observations of the early universe and a host of existing data that need to be analysed, to cosmic ray physics where the successors of the Pierre Auger Observatory and of Hi-Res will take a long time before

being able to improve on them by one or so order of magnitude. In any case, the very close interrelation between the three fields, nuclear physics, astrophysics and particle physics implies that the new research centre should welcome talents and skills in each of the three fields and be in principle open to researchers active in these.

AFTER FUKUSHIMA[2]

Nuclear energy is a major issue in the economy and geopolitics of today's world. It has different implications for developed and developing countries. The recent Fukushima accident has triggered a series of gut reactions around the world that call for comments.

Brief overview of the situation in developed countries

Nuclear physicists of my generation have grown up as scientists together with the development of nuclear plants and other peaceful applications – as we used to say – of nuclear energy. A decade later, we witnessed the birth of Aurelio Peccei's Club of Rome and the first expression of serious concerns about *"The Limits of Growth"*. We had strong convictions at that time: nuclear electricity would solve the problem of the vanishing reserves of fossil fuels and provide the key to the exponentially growing needs of the planet. Within a few decades, nuclear fusion would follow, presenting humanity with a clean and infinite source of energy. We were of course aware of the severe safety requirements implied by the operation of nuclear reactors but we thought that we were able to handle them and that, with time, we would keep improving our mastering of nuclear energy. Hiroshima and Nagasaki had left a deep mark on all of us, but we expected that the pacific use of nuclear energy would be able to exorcise the devils and that nation leaders would be wise enough to never use nuclear weapons any longer. Last, we considered that it was our duty to educate the public and demystify the fear provoked by the potential danger of invisible and strongly damaging radiation. We thought that we should be able to do so.

For the many years that followed, we stood by our beliefs and remained convinced that nuclear energy was indeed good for the planet. Yet, we had to admit that our vision of the future had been somewhat naïve.

It soon became clear that the stable containment of hot plasma inside tokamaks was much more difficult than anticipated. When I graduated, in 1958, fusion scientists were trying to convince us that we should join them because fusion would save the world: it was the energy of tomorrow and the problems it was facing should be solved in less than 20 years. Over half a century later, nobody would dare to quote a date for such an event; nobody would even dare to assert that we shall ever be able to control nuclear fusion.

Problems that had not been seriously anticipated appeared in the management of nuclear plants. Most important has been the question of radioactive nuclear wastes: what should be done with the spent fuel? Keeping safely such extremely hot material for centuries and making sure that it would never contaminate the environment, are difficult problems that have not yet received a satisfactory solution. Spent nuclear fuel is currently kept in pools, which had been designed for temporary storage, for much longer than was anticipated. We have seen in Fukushima that such pools are an additional potential danger when adequate cooling can no longer be supplied.

The decommissioning of nuclear reactors having reached the end of their lifetime has turned out to be far more expensive and time consuming than had been anticipated and the temptation is strong to keep plants running beyond their planned maximal age in spite of the presence of defaults such as cracks in the structure.

Accidents involving partial melting of the reactor core have occurred. Among the most famous are Three Mile Island, Chernobyl and, now, Fukushima. Radioactive material leaking out of the core to the environment is the main – one might say the only – serious risk in a nuclear accident. The worst case was

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by far Chernobyl where evacuation of the contaminated zone was not decided early enough and, more importantly, where a cloud of radioactive material ejected into the atmosphere contaminated significant areas in neighbouring countries, in particular Belarus. There are always lessons to learn from such accidents and the awareness of the importance of safety has kept increasing over the years. As a result, reactor designs of successive generations have been paying an ever increased attention to safety.

Originally, uranium reserves had been considered sufficient to never become a problem. With time, however, the cost of mining increased faster than had been expected and new sources of ore, including extraction from sea water, are currently being explored. Breeder reactors have been developed, which produce more fissile material than they burn, thereby offering attractive contributions to the solution of both problems of waste storage and fuel reserves. However, today, their exploitation remains marginal.

Currently, something like 14% of the world electricity is produced in nuclear plants. It is less than had been expected because the needs in energy have increased more slowly than anticipated and because new sources of fossil fuels are being exploited, albeit at significantly higher cost than earlier sources.

The Anti-nuclear Movement

There is some irony in recalling that the anti-nuclear movement started in 1950 with the Stockholm Appeal, which was signed, in the wake of its initiator Frederic Joliot-Curie, by many scientists, intellectuals and artists. The appeal was calling for an absolute ban on nuclear weapons. The anti-nuclear movement progressively expanded to include nuclear energy, which has become today its main soap-box. It is not my intention, in the present article, to analyse the arguments put forward by tenants and opponents of the nuclear cause but I wish to comment upon the unanticipated success of the anti-nuclear movement and the major role it has been playing in slowing down the development and progress of nuclear energy. Whether the arguments that have been used are right or wrong has become somewhat irrelevant. What matters is their political strength.

A healthy management of nuclear energy at the world scale implies the support of a responsible and adult society, well aware of the potential danger of nuclear technology, committed to constantly improving the control it has over it, accepting to spend sufficient resources to this aim and to invest in R & D in order to solve the problems that it is confronted with, such as safety, nuclear wastes and fuel resources. Whether we like it or not, such a society does not exist.

No one may decide for the majority what is good for them. Who tries to do so, however generous his motivation, will simply appear as being arrogant. One may not impose nuclear energy to a society that rejects it. Never mind if it is for bad reasons, irrational and emotional, nuclear technology cannot be imposed to a hostile and adverse society. The recent Fukushima accident has given an opportunity to measure the aggressiveness and incomprehension that characterize the dialogue between pros and antis. The earthquake and subsequent tsunami killed over twenty-five thousand Japanese, but the media focused on Fukushima in spite of the fact that it had not yet made a single victim.

The surprise in Fukushima was the strength of the tsunami, not the nuclear accident. But a nation leader as respectable as Angela Merkel used it as an incentive to declare a moratorium on nuclear energy in her country. She is a competent and well informed person; she knew very well the risks inherent to the exploitation of nuclear plants; she is a responsible leader; she understands what is implied in assuming such risks; she knows that if tsunami and earthquakes are unlikely to occur in Germany, the terrorist threat of an attack against a nuclear plant is always present and ubiquitous. Nothing of the Fukushima accident should have made her change her mind on an issue of such an importance to the economy of her country. Yet, it did. Nation leaders do what they think is good for their country, never mind whether it is rational or not. Politics is often irrational.

It is clear today that we, physicists, have badly failed in our earlier ambition to exorcise the devils attached to nuclear technology. The idea that proper information could eradicate the deep rooted fear of nuclear radiation and the gut reaction that it entails turned out to be wrong. We must now draw the consequences. The hostility against nuclear energy has already been extremely detrimental to its progress.

Several countries have placed a moratorium on nuclear energy and strongly reduced resources devoted to the training of new nuclear physicists and engineers. R & D on breeders has been stopped, or at least severely slowed down, in spite of the large resources that had been invested into its development. Such decisions can be taken overnight but to recover from the delay which they are causing takes a decade. In recent years, when global warming had been used by the nuclear industry as an incentive for a *"nuclear renaissance"*, it became clear to many countries that much time had been lost in slowing down their progress. Today, after Fukushima, who knows what will happen of this announced renaissance?

The western world is now split in two clans that fight each other and have become unable to dialogue. Any statement made by the tenants of nuclear energy has become suspicious to the majority. Fukushima has been efficient at revealing how deep the antagonism is. Under such conditions, we may indeed wonder whether there is a future for nuclear energy in the West.

Controversial issues

It is instructive to review briefly the main controversial issues.

One of importance is the evaluation of the number of deaths caused by major nuclear accidents. It is always disturbing to deal with deaths as if we were accountants, but the point is that direct deaths are relatively few, indeed negligible, when normalized to Gigawatt hour, in comparison with those induced by the coal and oil energy production chains. Controversy appears when dealing with the long term. Radiation, like many chemical pollutants, may induce cell damages that get improperly repaired, resulting in cancers or malformations that may only be revealed in the next, or after-next, generation. The study of such effects can only be statistical and requires a long waiting time before reliable conclusions may be drawn. They invite bad faith and controversial statements from both those who want to minimize such effects and those who want to dramatize their consequences.

A second cause of controversy is the perceived lack of transparency in communication. When nuclear energy is in the hands of the State, the State is suspected to hide the truth for reasons of national interest; when it is in the hands of private industry, private industry is suspected to hide the truth for reasons of financial interest. In spite of the establishment of numerous independent control institutions, the confidence of the society in official statements has kept decreasing with time. A blatant demonstration was given on the occasion of the Fukushima accident; and when you do not know whom to believe, you prefer to sit on the safe side.

A third concern expressed by the anti-nuclear clan against nuclear power is proliferation, namely the fear that expertise in nuclear technology be used to manufacture weapons. Such a concern has been determinant in slowing down and often stopping the development of fast breeders. How serious it is remains controversial.

Many more issues are subject to controversy, such as the already mentioned problem of nuclear waste storage or the unbalanced way in which the anti-nuclear clan, and in particular institutions such as Greenpeace, deal with nuclear energy in comparison with fossil fuel energy or, even more so, with renewable energies.

Before leaving the subject it is worth mentioning that nuclear energy, although being in the limelight, is far from being the only matter of concern in the field of nuclear technology. The problems posed by the neutralization of the existing arsenal of nuclear weapons – numbers between 30'000 and 40'000 are commonly quoted – are enormous and have not yet found a satisfactory solution.

The fear that terrorists might assemble nuclear weapons is a major concern. It spans a broad spectrum ranging from poisoning individuals with radioactive Polonium, as was done in 2006 to Alexander Litvinenko, to the threat by Al Quaida that if Osama Bin Laden were captured or killed a nuclear bomb would explode somewhere in Europe and trigger a "nuclear hell-storm".

Negligence and incompetence may have terrible consequences. Several cases of lethal radiation overdose given mistakenly to patients by radiotherapists have been reported. Finally, one should remember that millions of radioactive sources are currently used today for research, industrial or medical purposes. A few permil of these are orphan sources, of which one has lost track.

Which lessons for Vietnam?

Developing countries, and in particular emerging Asian countries, are generally including nuclear energy as an important element of their development. It seems obvious, from the above overview of the situation in the West, that they have much to learn from the experience of developed countries in terms of what should be done technically and of what should not be done politically.

I can illustrate simply the disparity between the interests of developed and developing countries by referring to an interview that I was watching on television in the wake of the Fukushima accident. A young Canadian lady, somehow associated with Greenpeace if I well remember, was explaining that Fukushima made it clear to the world that nuclear energy had to be abandoned; when asked by what it should be replaced, she mentioned renewable energies, such as solar and wind, and insisted on the need to save energy by taking positive actions such as thermally insulating our homes. That's all fine and even somewhat romantic. Nobody would deny that we should avoid wasting energy and that solar and wind energies should be used wherever it makes sense to use them. The point she was missing, however, is that the average Canadian consumes 27 times more electricity than the average Vietnamese, 38 times more than the average Indian, 122 times more than the average Bangladeshi and 500 times more than the average Ethiopian. Such disparity makes her statements obviously irrelevant to those who do not have the good fortune to live in the more privileged parts of the world. Her giving lessons to them would simply be indecent.

Developing and emerging countries need urgently new energy sources in order to catch their delay and maintain a high growth rate. The scale of the problem is such that nuclear energy, at least for a few decades to come, is the only realistic solution. The nuclear debate that is taking place in developed countries is unlikely to be of any relevance to them.

Indeed, India has launched a vigorous programme of fast and thermal breeders in spite of the concerns that such technologies have triggered in developed countries in terms of safety and proliferation. In China, by around 2040, Pressured Water Reactors are expected to level off at 200 GW and fast reactors to progressively increase from 2020 to at least 200 GW by 2050 and 1400 GW by 2100. This planned development may slow down a bit after Fukushima, but only a little bit. China is facing gigantic demands in energy and has essentially no other choice than nuclear. Concerns have been expressed that too rapid a development might have dangerous consequences: under pressure, one might be tempted to cut corners and compromise on safety, to prefer a cheaper and less safe solution to a more expensive and safer one; time will be short to train a sufficient contingent of skilled and experienced staff; corruption, which is often present in emerging countries, remains a threat with the recent example of the former head of the China National Nuclear Corporation having accepted a sum of nearly one million USD in bribes.

Such is the environment in which Vietnam is launching its nuclear energy programme. It is obvious that it must do it with all the rigour, competence and skill that are required. Those who will bear responsibility in such an endeavour must be well aware of the issues that are at stake and have a deep knowledge and understanding of the situation. It is a formidable challenge for the country to train the physicists, engineers and managers who are needed for the success of such an ambitious project.

Vietnam cannot be compared with China or India. Any issue related to nuclear energy will have to be considered within the framework of its specific economic, technological and social situation. It is essential and urgent to identify those which Vietnam is prepared to address and those where additional expertise may be required. Many difficulties will have to be faced; the danger of forsaking national independence to foreign nations is not the least. The pool of talented staff having today expertise in nuclear technology must be carefully assessed in order to evaluate without delay the scale of the intensive training that is undoubtedly required. The population needs to be properly prepared to understand and accept the decision to launch an important nuclear programme. The short and long term financial consequences need to be well understood in the current economical context of the nation. The planning of the project must condition each of its steps to the guarantee that the country be ready to achieve it successfully.

No decision can be copied from other countries. Each issue has to be assessed and understood within the peculiarities and specificity of the Vietnamese situation. Many choices will imply difficult decisions to be taken. It will not always be clear which the right one is. Just swap the first two letters of *nuclear* and you get *unclear*…

NUCLEAR POWER: FURTHER COMMENTS[3]

In a recent article, I commented on reactions expressed in the wake of the Fukushima incident and I tried to spell out some lessons which might be drawn from it in the Vietnamese context. In answer to comments triggered by this and other articles, I have been asked by Tia Sang to state more clearly my views on the opportunity for Vietnam to enter the nuclear power club, in particular in reference to the recent ministerial IAEA conference on nuclear safety held in Vienna from 20th to 24th June, 2011.

Allow me first to briefly restate the points I was making in my earlier article. In the western world, the Fukushima incident has revealed an aggressiveness against nuclear power which, although largely irrational, can no longer be underestimated. The lack of a responsible attitude toward nuclear power implying determination to learn how to master it rather than fighting it, may have reached such a level that one better might give it up altogether. One cannot impose nuclear power to a society that rejects it. In Asia, however, in particular in China and India, the arguments developed by the western anti-nuclear clan in favour of giving up nuclear power are of little value. Developed countries are spending typically an order of magnitude more electric power per inhabitant than emerging countries: they have no lesson to give on saving energy and investing extensively in so-called renewable energies. Whether one likes it or not, India and China will develop their nuclear power programmes. In such a geopolitical and economical context, it is natural for Vietnam to join the club. However, it is a formidable challenge for the country to get prepared and, for the time being, one has not yet seen signs that this challenge is being addressed with the necessary determination.

It is not to me to say whether Vietnam should or not embark on a nuclear power programme, this is a political decision which implies a vision of the geopolitical and economical future of the country which is beyond my knowledge and competence. What I may state, however, are my views on the conditions which Vietnam should fulfil in order to guarantee a safe operation.

Quoting from my earlier article, "*Any issue related to nuclear energy will have to be considered within the framework of its specific economic, technological and social situation. It is essential and urgent to identify those which Vietnam is prepared to address and those where additional expertise may be required. Many difficulties will have to be faced; the danger of forsaking national independence to foreign nations is not the least. The pool of talented staff having today expertise in nuclear technology must be carefully assessed in order to evaluate without delay the scale of the intensive training that is undoubtedly required. The population needs to be properly prepared to understand and accept the decision to launch an important nuclear programme. The short and long term financial consequences need to be well understood in the current economical context of the nation. The planning of the project must condition each of its steps to the guarantee that the country be ready to achieve it successfully.*"

It is not useful to be critical, one must be constructive. This is what I tried to be when I wrote these lines. But reading between the lines, it is clear that one has the (possibly wrong) impression that, up to now, none of the above recommendations has been seriously addressed with the required energy. If some have, it is not sufficiently visible to the public. Each of the above issues should be the object of a plan, which should be properly advertised. Concerns might rightly be voiced that it is a bit late to do so. It is clear that, long ago, a serious training plan could have been drawn, measures to recruit skilled talents could have been taken, an Institute could have been created where the scientists, engineers and managers who will run the plant could have been trained and brought to maturity. But better late than never.

[3] Published in Tia Sang, 20 August 2011.

The public cannot be kept out, we have learned how important is its acceptance of the national nuclear policy. How to inform and imply it successfully is less clear, we failed to do so in western countries.
Fukushima has had a strong psychological impact (not to mention the lessons drawn from the consequences of the tsunami). Vietnam should take advantage of the conclusions of the Vienna Conference to strongly rely on foreign expertise to assess its preparedness. In particular, it is stated that *"it is imperative for new countries embarking on nuclear programmes to fully implement IAEA Safety Standards, to integrate lessons learned from the Fukushima accident into the development of their programmes and to demonstrate complete preparedness to operate nuclear power plants before commissioning the first reactor"*. It is also stated that *"IAEA could assist in carrying out peer reviews of national safety reviews, using the services of international expert teams and make the results publicly available. This could enhance the openness and credibility of national safety reviews."*
Vietnam cannot afford to ignore such encouragements, it must make extensive use of foreign assistance and competence, it must manage its entry into the nuclear programme in complete transparency. Lacking to do so might lead to disaster. Having the arrogance to think that Vietnam does not need to demonstrate its preparedness to the world before entering the game would simply be criminal.

NUCLEAR POWER AND COMMUNICATION[4]

Recently, in the wake of the Fukushima incident, opinions have been expressed in the Vietnamese population about the opportunity for Vietnam to equip itself with nuclear power. At the same time, the Government has become increasingly conscious of the need for an objective and efficient communication with the public on such important issues. This is a very positive step as the implications of adopting nuclear power must be understood and accepted by the population for a serene and dispassionate use of this form of energy to be possible. In many foreign countries, the split that has taken place in the population between pro- and anti-nuclear movements has resulted in irrational and sterile exchanges between the two clans and in a growing mutual aggressiveness that has been very detrimental to an efficient exploitation of nuclear plants.

Fortunately, in Vietnam, it is still time to prevent such a split to occur by establishing as soon as possible an efficient system of communication. For it to be profitable to all, it must be done in a spirit of mutual respect and be objective: one should not distort or hide information. With the globalization of information through Internet, sooner or later the truth is revealed. It is essential for the Government to learn which are the concerns that may worry the population; it will then be able to provide the proper information that will help dissipating such concerns if they are unfounded. And if they are founded, it will possibly reconsider the time table in order to take steps that will guarantee that such concerns are well taken care of.

Communication must cover a broad spectrum for it to be useful and efficient. The problem is complex, making too narrow an approach inadequate. The population must understand the importance of the growing energy needs of the country, the danger that it becomes dependent on others, the economic and geopolitical issues that are at stake. There are enough convincing arguments to make it clear that joining the nuclear club is a good option for Vietnam from that point of view. At the same time, the population must be convinced that the country is sufficiently prepared to the event to guarantee the safe conditions that are required by the operation of such a high tech and potentially dangerous technology. In particular, it must be convinced that the human resources that are necessary to success are available in the country with proper training and expertise. One should not underestimate the dangers, one should, at the same time, recognize that nuclear power, together with hydroelectricity, is, by far, the energy that costs the least human lives per GWyear. One should make it clear that the implications of potential natural disasters, such as earth-quakes, tsunami or floods, have been carefully studied and well taken care of. At

[4] Published in Tia Sang, 5 October 2011.

the same time, one should not forget that the Fukushima incident has not directly caused any death in an environment where some 25'000 lives have been lost.

It is of course the substance, more than the form, that matters in communication. But the form has also its importance. Communication is not propaganda and it is important to prevent communication channels, such as newspapers, magazines and TV, to be perceived as tribunes sold to the interest of a single clan. Care must be taken, when an opinion is expressed that is not shared by a vast majority, to give a chance to those who think differently to expose their views. Communication must be used to educate and dissipate misunderstandings, not to impose single-sided opinions. Failing to do so would generate conflicts that would deeply harm the nuclear cause.

All these comments are pure common sense and are shared, I believe, by any observer looking at the question with an objective mind. What is important is to establish such communication as soon as possible in a spirit of mutual respect, serenity and impartiality.

UNIVERSE IN A NÓN[5]

The recent discovery of the Higgs boson at the CERN Large Hadron Collider (LHC) is a major achievement of contemporary science. Having contributed, over many years, to the conception and development of the LHC and of its detectors, I followed the event with emotion. The project had been conceived some thirty years ago and has kept a generation of young particle physicists busy for what has turned out to be the main part of their scientific life. Such a dedication to a single endeavour over so many years is unusual in science. It takes a lot of energy, determination and confidence in the success.

The physicists who presented the results of the Atlas and CMS collaborations, Fabiola Gianotti and Joe Incandela, were two of my younger colleagues in the UA2 experiment of which I was spokesman, in the eighties. When Fabiola joined us, she was a young PhD student. I remember having taken a night shift with her at the accelerator; a storm had caused a power failure and we had no beam for a long time. There was nothing to do but wait. She had a book with her, *Finnegans Wake*, by James Joyce. We had a long discussion about James Joyce and *Ulysses* and I was very impressed by her: when I was her age, I did not even know who James Joyce was. Joe joined as a young postdoc, he had been searching for Dirac monopoles for his PhD in Chicago, he did not find any but set strong constraints on their possible existence. I remember having visited him at that time, it was a tabletop experiment, basically a large wire loop, on which he was working essentially alone. Now he works with thousands of collaborators…

Fabiola and Joe, now spokespersons of their respective experiments, illustrate well the long trajectory followed by so many physicists and engineers over three decades. The road to success has been long and difficult. Both collider and detectors are achievements of an extraordinary complexity, at the top of the state of the art in all of their features, and their remarkably smooth running forces admiration. They perform beyond any expectation; no one could have been sure that they would work at all, so big was the challenge. Their success demonstrates the efficiency of Big Science, as one calls it, sometimes not without contempt, when it comes to explore the frontiers of contemporary science, whether particle physics or astrophysics. What a happiness it is to see the hard work and perseverance of so many young skills and talents being so beautifully rewarded!

To whom is not familiar with particle physics, it may be difficult to get an idea of the importance of the event and to call the Higgs boson the "God particle", as one does in some media, is not particularly helpful.

Let us start by having a broad view of how physicists see the world today. They see it as being made of building blocks which they call elementary particles. The electrons in an atom and the quarks in the protons and neutrons that make atom nuclei are the most common of these building blocks. Everything in the Universe, stars, galaxies and us, is made of these. Their sizes are very small in comparison with human scale: one billionth of a micron. When one looks at objects at such a small scale, one finds that

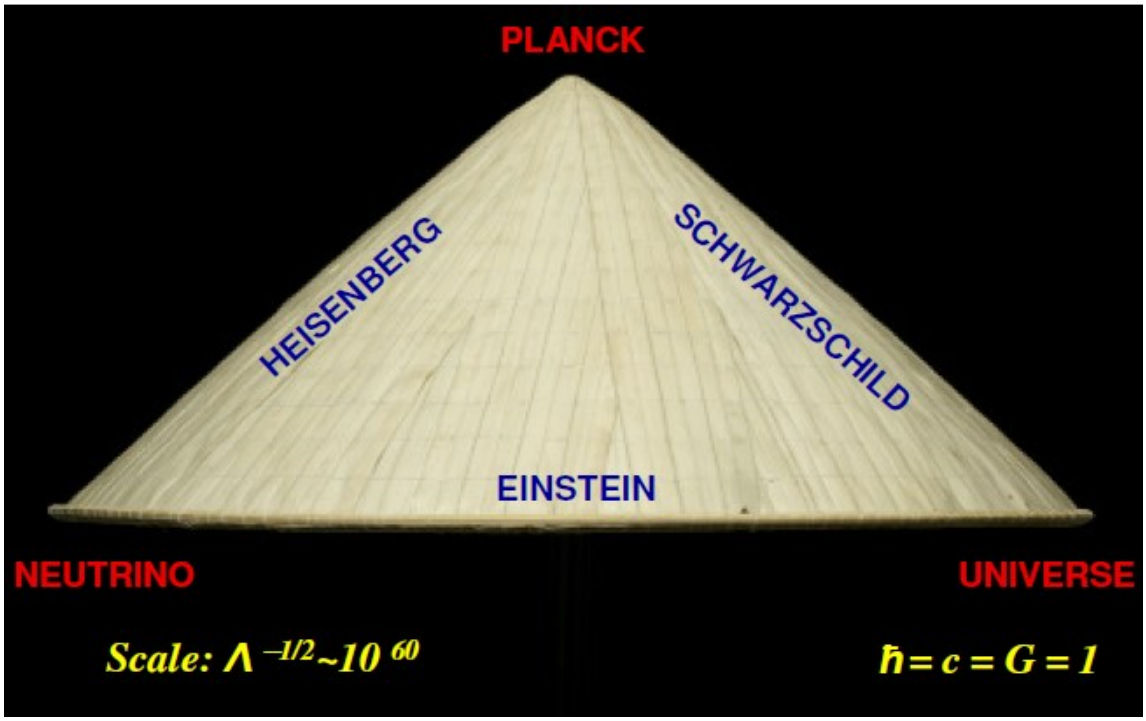
[5] Published in Tia Sang, 20th July 2012.

they behave in a very strange way, half way between particles and waves: one is forced to give up both concepts and to replace them by a new one: this is the world of quantum physics. A quantity, the Planck constant, written $\hbar$, sets the scale at which quantum effects can no longer be neglected. For objects made of elementary particles, such as protons and neutrons, the product of their mass by their size cannot be smaller than $\hbar$. This statement, referred to as the Heisenberg uncertainty relations, sets therefore a limit to the physical world: the Heisenberg limit.

On the contrary, when one looks at the world at the larger scales, say at the scale of the Universe, gravity dominates while it was negligible at quantum scale. Gravity was first described by Newton as a force proportional to a universal constant, written G. When, at the end of its life, a star collapses under its own weight, it may reach a state, if it is heavy enough, where gravity has become so strong that nothing, not even light, can escape it. One speaks of a black hole and one calls its radius the Schwarzschild radius after one of the physicists who described such states. The Schwarzschild radius is proportional to the mass. That of the Sun is 3 km but the Sun is not heavy enough to reach such a small size when it will die: it will never become a black hole. For an object of a given mass, it makes no sense to talk of dimensions smaller than that of the black hole. This sets another limit to the physical world: the Schwarzschild limit. While on the Heisenberg limit the product size×mass is constant (and equal to $\hbar$) on the Schwarzschild limit it is the ratio size/mass which is constant (and equal to G).

The intersection between the Heisenberg and Schwarzschild limits corresponds to a size of $\sim 10^{-33}$ cm and a mass of $\sim 10^{19}$ proton masses. It is called the Planck scale. At that scale, quantum physics and gravity, as we understand them today, are incompatible: to describe what happens there, we need a new theory of which gravity and quantum physics would be simple approximations that apply in their own domains. For now several decades, many theorists have devoted time and effort to the quest for such a new theory, the basic elements of which, called strings, are at Planck scale. Much progress has been accomplished, but much more remains to be done. It is also at Planck scale that the Big Bang took place: what happens at Planck scale is probably the main unsolved mystery of today's physics and one may hope that solving it will, at the same time, solve many other, probably less fundamental, mysteries of physics.

It is convenient to express lengths and masses in units of the values they take at Planck scale. If, in addition, one expresses velocities in units of the speed of light, any physical quantity becomes a pure number. One may illustrate this in a diagram in the form of a nón: the Planck scale is at its tip, the sides are the Heisenberg and Schwarzschild limits. For a mass m and a size l, the Heisenberg limit axis measures $log(l/m)$ and the Schwarzschild limit axis measures $½log(lm)$. In such a diagram, lines of equal densities are parallel to the base of the nón, at 45^o to each of the Heisenberg and Schwarzschild limits. The Universe, more precisely the visible Universe, sits on the Schwarzschild limit. Indeed, as the Universe is expanding, the more remote a galaxy is from us, the faster it is recessing. We cannot see farther than the distance at which the recession velocity reaches light velocity, we call this the "horizon" and when we say "Universe" we really mean the visible Universe, that part of the Universe that is within the horizon. While the Schwarzschild limit is the home of black holes, the Universe is not a black hole. A black hole is surrounded by emptiness while the visible Universe is surrounded by more of the same, but invisible to us. In pure numbers, the mass and size of the Universe are equal and amount to 60 orders of magnitude, 10^{60} Planck masses and 10^{60} Planck lengths. The density of the Universe, mass divided by the cube of the size, is therefore 10^{-120}. This is the density at the base of the nón.



Three limits to the physical world (Quantum, gravity and dark energy) and their intersections (Planck scale, Universe and "neutrino"). See arXiv physics.pop-ph 1201.0961.

We do not understand what the Universe is made of, stars and gas clouds account for no more than 4% of its mass. This is another major mystery of contemporary physics. But whatever it is made of, we call it "dark energy", is well described in general relativity by a single number, Λ, called cosmological constant. In our system of units, the dark energy dominated density of the Universe is $\Lambda/8\pi$, meaning a cosmological constant at the 10^{-120} scale. The base of the nón sets therefore a third limit to the Universe. One finds on it, on the side of the Heisenberg limit, the lightest of all known elementary particles, the neutrino. Whether this is an accident or has a deep meaning is unclear.

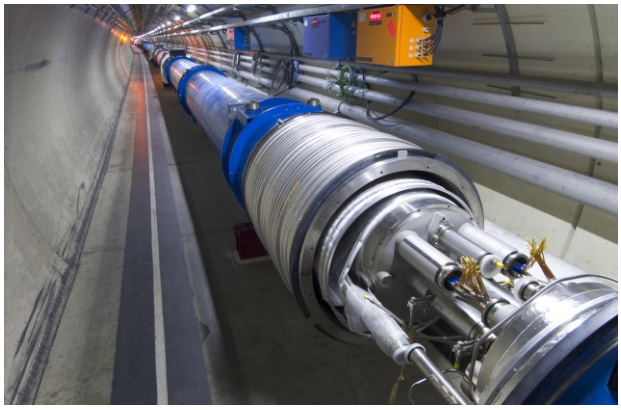
Where does the Higgs boson fit in such a picture?

When we look at smaller details, we unravel new mysteries. In the domain of gravity, dark matter and what happened just after the Big Bang, a sudden inflation of the Universe, are among the most puzzling. In the domain of the quantum world, the mass generation mechanism plays the leading role. The elementary particles which we know are extremely light: the mass of the heaviest of these, called the top quark, is only $\sim 10^{-17}$. One might then think that a world of massless elementary particles should be a good approximation to the real world. Of such a world, we have a remarkably simple and beautiful picture based on a very few basic principles: space-time symmetry with respect to rotations and translations (the Poincaré group), exchange symmetries between identical particles having again a group structure (SU(3) for the strong interaction and SU(2)×U(1) for the electroweak interaction) and what we call gauge invariance, meaning that the laws of physics do not depend on the particular values taken by some phases inherent to quantum physics. The predictive strength of such a theory is amazing: it requires the existence of the photon, the weak bosons and the gluons and has been verified to a precision better than a percent by hundreds of independent measurements.

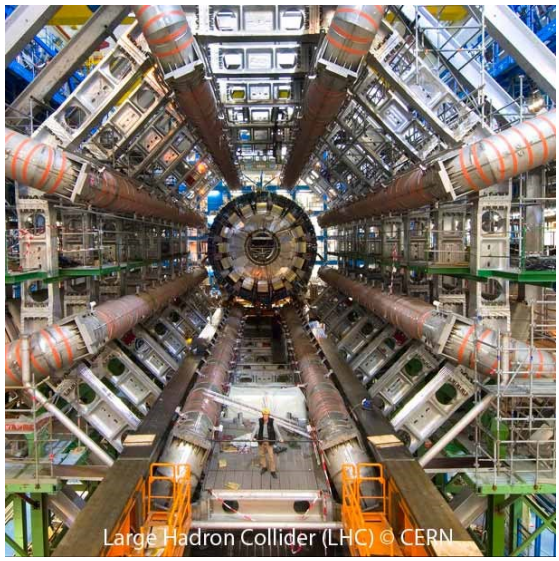
Yet, this theory does not tolerate the least deviation from zero of the elementary particle masses. As soon as one sets them to the values they take in the real world, however ridiculously small they are, the theory collapses: one must modify it to accommodate non zero masses. The simplest and most economic way to do it is to introduce a new particle that has the peculiar property of interacting with all other particles with strength proportional to their masses. This particle, abusively called the Higgs boson, was postulated in 1964 by six physicists, Robert Brout, François Englert, Gerald Guralnik, Carl Richard Hagen, Peter Higgs and Thomas Kibble. It has spin zero, one says that it is a scalar, while all other elementary particles have spin one or one half. Its beauty arises from the fact that it gives masses to elementary particles in relation with a small imperfection of the electroweak SU(2)×U(1) symmetry: it is the slight breaking of this symmetry, which is observed in the real world, which naturally implies non zero masses for elementary particles. The idea that governs this mass generation mechanism being very general and elegant, one speaks of spontaneously broken symmetries, it was immediately accepted by the scientific community as the most likely mechanism adopted by Nature. While the theory predicts the details of the interaction of the Higgs boson with other elementary particles, it does not predict its mass with precision: this motivated the construction of the LHC covering a broad enough energy range not to miss the Higgs boson if it exists.

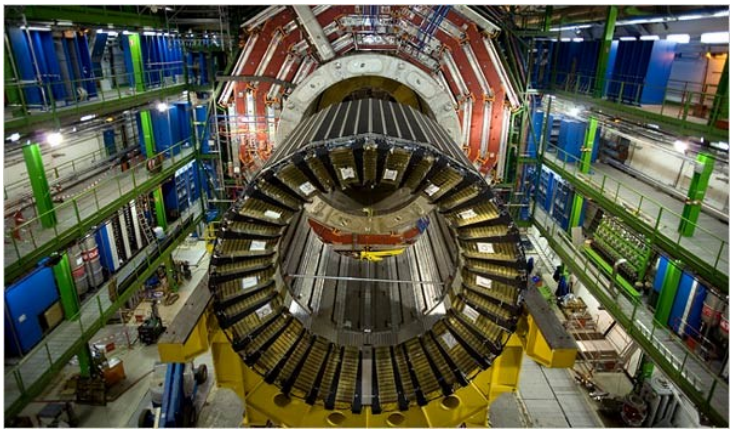
The particle that has now been found at CERN fits well in this model: it was searched for having in mind all the properties predicted by theory for a Higgs boson. Yet, more checks will be necessary to consolidate the discovery and ascertain that the particle that has been discovered behaves precisely as a scalar Higgs boson is supposed to behave. Moreover, the mass generation mechanism resulting from the spontaneous breaking of the electroweak interaction is very general and could materialize in different forms, more complex than a single Higgs boson. In particular, a very popular theory that includes a new, hitherto unobserved symmetry of Nature, called Supersymmetry, would require the existence of five Higgs bosons. Four more would still be hiding at higher masses, waiting for LHC to unravel them.

In summary, the discovery announced by CERN, while it still needs to be placed on firmer bases, is most likely the first evidence for spontaneous symmetry breaking to generate the tiny masses that elementary particles are observed to have. It opens the door to a series of new searches, for additional Higgs bosons, for particles implied by Supersymmetry or for new objects that have, until now, escaped our imagination. The perspective of new discoveries in the exploration of a new domain of particle physics is a well deserved reward for all those who dedicated decades of their lives to this endeavour. Let us wish for them many more successes!



The LHC collider ring with its superconducting magnets





The ATLAS (above) and CMS (below) detectors being assembled.

Fabiola Giannoti and Joe Incandela after their talks watching on a videoconference screen the audience of the particle physics conference taking place simultaneously in Melbourne

NUCLEAR REACTORS ON BOARD LARGE SHIPS: IS IT THAT CRAZY?[6]

I recently attended the 46th session of the International Seminars on Planetary Emergencies that included a host of very interesting contributions. I choose here to present a case that may sound crazy at first glance but that deserves, in my opinion, more serious attention. It was made by Robert Petroski and Lowell Wood with the title: *"Ship-based Nuclear Energy Systems for Accelerating Developing World Socio-economic Advances"*.

Such systems have already existed for decades in the form of submarines, airplane carriers, ice breakers, etc... However, they are of relatively low power, well below 100 MWe, and burn expensive enriched fuel. There are also projects such as the Power Systems Westinghouse project[7] offshore New Jersey, the Russian Rosatom Akademic Lomonosov reactor[8] in the Arctic, the French submarine Flexblue project[9], etc... but what is discussed here is different: one talks about ~1 GWe embarked and looks for economically attractive solutions.

The main attraction of such a scheme is the availability *in situ* of an infinite heat sink and the possibility to let water flow around the core, located below the water line, by simple gravity in case of loss of control. The Three Mile Island, Chernobyl and Fukushima incidents not only would have been avoided under such a scheme but also would not have implied, as in the two latter cases, large displacements of population. The second important attraction is the important scale savings obtained by standardising the basic reactor design, units being built in series in onshore factories and deployed wherever they are needed.

The authors are talking about carriers of the Valemax type – bulk carriers of 400,000 tons dead weight, 360 m long and 23 m below water line – currently built in large quantities by Chinese and South Korean shipyards (Figure 1). Their point is to give a proof of feasibility by showing that existing carriers are perfectly able to host GWe nuclear reactors. However, a possibly better optimized design could obviously be used. The carriers would be moored in 50 to 100 m deep waters and electricity supplied ashore via underwater power lines.

Figure 1. A Valemax carrier.

[6] Published in Tia Sang, 19(2013)24.

[7] Rod Adams, Offshore Power Systems : Big Plants for a Big Customer, http://atomicinsights.com/offshore-power-systems-big-plants-for-big-customer/

[8] Akademic Lomonosov, http://en.wikipedia.org/wiki/Russian_floating_nuclear_power_station

[9] Flexblue, http://en.dcnsgroup.com/energy/civil-nuclear-engineering/flexblue/

The authors claim that such plants would be immune to earthquakes and tsunamis. However, while this is true in deep water[10], shallow coastal waters such as found in North and South Vietnam[11] would mean anchoring the carrier far away from the coast, implying very long underwater power lines. The only region where deep enough waters can be found at acceptable offshore distance is on the Central coast between the Binh Dinh and Ninh Thuan provinces. This may be the weakest point of such a scheme, together with the resilience of the carrier to strong storms, typhoons being common in the South China Sea and rogue waves having been occasionally reported[12].

While existing nuclear propulsion ships have happily used Pressurized Water Reactors (PWR) for over 60 years, the authors advocate the use of low pressure reactors, such as advanced versions of Light Water Reactors (LWR) or liquid metal and molten salts cooled systems (lead, lead-bismuth or FLiBe). Such reactors do not require large containment structures, use passive decay heat removal, taking full advantage of the infinite heat sink of the sea, and are immune to the failure of off-site power supply. Moreover, their lesser complexity means reduced maintenance and minimal number of staff required to crew the plant.

Several cooling configurations are considered. One direct approach would be to transfer heat directly from the reactor to the sea via a heat exchanger while an indirect approach, that would keep reactor components from being directly exposed to seawater, would be to reject heat into an intermediate pool of fresh water below sea level.

Much of the report is dedicated to safety issues, using existing data from offshore platforms and nuclear propulsion ships. Risks, meaning the product of the probability of an event by its quantized consequences, are evaluated for various scenarios and found significantly smaller than for equivalent onshore plants. The main arguments of relevance are the gigantic volume of the sea and the large distance from populated areas. Together with the resilience to storms and rogue waves, already mentioned, the most questionable of their conclusions may be the consequence of releasing a large amount of radioactivity into the sea, which would be an environmental disaster. They base their arguments on the Fukushima experience in diluting radioactivity into the ocean but the fear of such a release would trigger a huge emotional reaction from fishermen and environmentalists, such as Greenpeace, which, even if largely irrational, might be fatal to such a project. Such has indeed been the case in Japan in the past[13]. Security and proliferation issues are also discussed but the problems they pose are not worse than for onshore plants.

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[10] Tim Bunting *et al.*, *The Science of Tsunamis*, http://www.slb.com/~/media/Files/resources/oilfield_review/ors07/aut07/science_of_tsunamis.pdf

Vu Thanh Ca, Earthquake and Tsunami Scenarios in the South China Sea,http://www.ims.nus.edu.sg/Programs/ocean07/files/vu1.ppt#261

http://www.firstpost.com/fwire/un-okays-south-china-sea-tsunami-warning-centre-105461.html

[11] Pham Van Ninh *et al.*, *Geostrophic and Drift Currents in the South China Sea,AreaIV: Vietnamese Waters*

http://map.seafdec.org/downloads/pdf/collaborative%20research/AreaIV_Vietnam/SCS_FRS4_19.pdf

[12] Cheung. H. Kim, *Offshore Non Linear Waves and Impact Loads*, http://www.eagle.org/eagleExternalPortalWEB/ShowProperty/BEA%20Repository/EnergyNews/pdfs/2010/October/wavepresentation

Steve Pennell and Wendell Brown, *Rogue Waves Challenge Ocean Theorists*, http://faculty.uml.edu/robert_gamache/UMassMarine/UmassMarine_Sept_04.pdf

Roger Grimshaw *et al.*, *Rogue Internal Waves in the Ocean : Long Wave Model*, http://www.lboro.ac.uk/microsites/maths/research/preprints/papers10/10-05.pdf

Tim Lovet, *Waves*, http://www.worldwideflood.com/flood/waves/waves.htm

Jerry Dennis and Glenn Wolff, *Freak Waves and Rogues*, http://robinstorm.blogspot.com/2007/10/freak-waves-and-rogues.html

Bill Baldwin, ttp://www.mowwnj.com/www.MOWWNJ.com/Member_Articles_files/Destroyer%20Duty%20in%20Vietnam.pdf

[13] Tatsuo Masuda, private communication.

Economics is an essential motivation in the consideration of ship-based plants. Quoting from the authors: *"Of very substantial – possibly determinant – significance is that the nature of the nuclear energy systems that we contemplate and the services that they prospectively provide have an unusually large 'pay-as-you-go' aspect, allowing developing world markets to tender for developed world types and qualities of large scale energy services just when and as they can be afforded and paid for on a 'cash&carry' basis, without extensive infrastructure capitalization and creation far in advance, without having to 'buy more than you actually need due to quantization issues', etc..."*. Shipyard based serialized construction of floating nuclear energy systems comprised of standard modules have the potential to reduce all major component costs below the best-example values for land-based nuclear power plants. Very convincing arguments are developed by the authors for the overwhelming advantages of the scheme in terms of cost savings.

It must be already obvious to the reader that such an approach must be contemplated at regional level to make sense. It must be an opportunity to federate contributions from all countries sharing the banks of a same sea, some bringing their know-how in reactor design, some in shipyards, some in ore mining, some in fuel preparation, etc... It gives the enterprise a geopolitical dimension in addition to its technical, economical and social dimensions. It triggers innovative thinking in many domains on topics of utmost importance for the long range future of the region. In particular, in the present case of the South China Sea, it invites looking ahead beyond the present tensions into a future where all the concerned Asian nations would join effort for a sustainable energy policy.

LETTER TO THE MINISTER OF SCIENCES AND TECHNOLOGY[14]

Pierre Darriulat
darriulat@vinatom.gov.vn

Dear Minister Quân,

One and a half year ago, I sent you a letter of which I copy below the main points (Annex 1). If I were to write it today, I would use the very same words.

I am alarmed to see the lack of a clear training policy in the country for what concerns nuclear matters and the gigantic waste of money that results. This deep concern motivates my writing to you, in confidence in order to avoid making unnecessary waves.

Enormous resources have been distributed by the Prime Minister to his Ministers without having in mind any clear plan of how to spend them, without having in hand any clear tool that might ensure coherence and synergy between the projects that use them.

I may quote as an example the way in which the Minister of Education and Training is spending such resources (Annex 2).

Another event that illustrates the complete lack of control of the situation is the refusal by the Da Lat province to host the national Training Centre that is being planned and that should be the site for a modest research reactor. If we are unable to educate a small provincial People Committee, what about the population of the country when it comes to GWe reactors?

I am convinced that if we keep behaving so incompetently, the time will come when the country will be in danger of having to face two major problems: that of having its energy resources effectively in the hands of foreign nations and that of hosting a Chernobyl-like nuclear disaster.

It is never too late to react, even if it is becoming increasingly difficult when time passes by.

There must be a single Central Organisation that helps the Prime Minister to manage the issue competently and efficiently and has full responsibility to do so. Such were the Atomic Energy Commissions in the US and in France at the time when their nuclear programmes were being

[14] Sent in confidence in September 2013

implemented for the first time. The Ministry of Education and Training is so notoriously incompetent and paralysed by bureaucracy that one should not trust it to play an important role. An urgent task is to make a list of topics in which to train people in priority (Annex 3) and to make an inventory of the Vietnamese people in the country and abroad, including Viet Kieus having lost their Vietnamese nationality, who have competence in teaching such topics. Universities are obviously unable, by lack of competent teaching staff, to provide the training that is required. It will be already difficult to find a single person for each of the topics listed in Annex 3 having the required knowledge and skill. This training must be centralised and aimed at an elite, trained as a team. Training technicians is also very important but is less urgent and should be organised under the responsibility of the Central Organisation once it is set up. One must stop leaving to each Ministry the freedom to decide how to spend training resources; their training programmes, if any, must follow guidelines given by the Central Organisation and must be approved by it before being funded.

Please, be convinced that my only motivation in writing to you and in making criticisms that may sound outrageous and out of place is to serve the interests of your country and of science: I have nothing to gain in saying what I say, indeed I am more likely to make enemies. You must also understand that while my views are shared, I am sure, by the vast majority of people having some familiarity with nuclear issues, they may suffer from ignoring political and/or geopolitical parameters of which people outside governmental circles are unaware. Moreover, what I know of what is going on is incomplete and superficial: I learn it by accident and I make no effort to be properly informed. I am familiar with the Country Report presented by Nguyen Thi Yen Nhin (VAEA) in April 2012 in Vienna at the Technical Meeting on Innovative Nuclear Education and Training, showing that your Ministry is well aware of the obstacles and challenges that have to be faced. Yet, the dysfunctions which I am denouncing are so blatant symptoms that they fully justify, in my opinion, being alarmed.

Please, be assured of my deep respect and of my willingness to help within my modest domain of competence,

Pierre Darriulat
Hà Nôi, Autumn 2013

Annex 1: Excerpt from the letter sent to you on the occasion of Têt 2012.

[...] I thought that you might appreciate my repeating in writing the main points which I developed during our conversation. I do it in full humility and not pretending at any privileged wisdom, but the views that I expressed are not only my own: they are shared by the vast majority of those who follow with interest the development of science and technology in the country.

On the Centre for Nuclear Studies that is being created in Da Lat, I insisted on the need to train a team, not individuals, to attract the best possible staff and students and to have more confidence in the skills and talents of the Vietnamese youth than one currently has.

Training a team means that students should not be sent abroad for too long periods. They should come back to the Centre after each of their stays abroad (typically a year or less) and take part in a continuous teaching and learning process. Such interaction and exchange of experience is the best way to create close links between the members of a team. It is important that such a team share a common culture in the domains of relevance to nuclear power at large. The Centre must follow closely the progress of the students when they are abroad and organize lectures and seminars with a strong participation of the students in teaching. It should invite foreign experts for short stays (typically a month) during which they would give lectures and interact closely with the students.

Excellence of the staff and of the students is mandatory. While expertise is obviously necessary, motivation and morality are at least as important criteria in the selection of the staff. You want to create a Centre animated by the desire to serve the country, not to serve the individual interests of its members. The selection of staff members and that of students should follow strict and transparent rules. I should

think that having an international advisory council and some foreign (not only Russian) participation in the selection boards would greatly contribute to success in this domain. You do not want a staff of technocrats, you want them to have broad views on what is implied in running a nuclear plant, including the importance of safety issues, of communication and interaction with the population, of knowledge of the geopolitical nuclear landscape in Asia, in particular in Japan, India and China, of open technical issues such as the treatment of nuclear wastes, the need for new sources of ore, the perspectives of advanced technologies such as breeders and accelerator induced fission and the issue of proliferation.

Attracting excellent students and staff implies having a long term plan (say next five years in detail, following five years in more general terms) for both human and financial resources. This is needed for talented and skilled individuals to feel confident enough in the seriousness of the initiative and in the motivation of the Government at giving outstanding support to the national nuclear effort. Such a plan should include a flexible enough contract policy, with a proper balance between the various kinds of fixed term and indefinite contracts. It should also guarantee competitive wages. As you well know, today, a young graduate having a master in marketing, or project management, or economics has a salary at least three times higher than an experienced university professor. Such practices are lethal to Vietnam.

The third point I mentioned concerns the need to have more confidence in the potential of the Vietnamese youth. For the first time since the foundation of the Republic, the young generation has not suffered of the wars that marked the recent history of the country and of the very difficult years that followed. They are the children of Doi Moi. Contrary to their parents and grand parents, they have had a chance to be given at home an education and training of a level comparable with that in other countries. One can expect an elite to emerge from their generation with a strong motivation to restore intellectual and moral values at the highest possible level. The country would greatly benefit in selecting and training such an elite using the strictest and most rigorous selection criteria and in giving them responsibilities and full support. This is a question which is close to my heart because I have lived next to Vietnamese students for now more than ten years and I have witnessed their motivation at reaching very high intellectual and moral standards. However, I did not feel that the country was prepared to give them the future that they deserve having.

These were the main points I mentioned. While I am convinced about what I say, it does not mean that I am right and I repeat that I said it in full humility. I know that much of what I suggest is very difficult to implement in the current Vietnamese environment because the heavy bureaucracy that paralyses progress in so many domains. It is late to create the Centre in Da Lat, but better late than never. It may be an excellent opportunity to create a Centre of excellence under significantly more favourable conditions than what we are used to. As you told me, in the present system, even Ministers cannot do what they would like to do. May I wish you, on the occasion of the New Year of the Dragon, in addition to health and happiness for you and your family, much success in promoting better practices in the management of science and technology in the country.

Please be assured of my deep respect and of my willingness to help within my modest domain of competence,

Pierre Darriulat, Hà Nôi, Têt 2012

Annex 2: Example of a request made by the MOET Committee for the training and development of human resources in the field of nuclear energy to a few selected Vietnamese Universities and a training centre.

On April 17th of this year, these universities and training centre received a letter requesting from them proposals for spending several billion dongs. The deadline was May 10th, less than a month later. This letter is available to the public.

Each university was encouraged to submit proposals for training projects funded at the level of 1 billion dongs each; the training centre was encouraged to submit proposals for documentation projects funded at the level of 1 billion dongs each; two universities were encouraged to submit proposal for the construction and equipment of laboratories dedicated to research and training in the domain of nuclear energy, at the level of 5 billion dongs per project.

The complete absence of guidelines from the Committee and the lack of competence in the universities being addressed will irremediably result in a waste of resources, the funds allocated being spent without any coordination and control. There is already evidence that such is the case.

Annex 3: A very tentative draft list of topics to be taught in priority in the national centre for the teaching of which at least one Vietnamese or Viet Kieu scholar or engineer having sufficient expertise should be identified for each topic. Items 1 to 6 are very basic and justify an average lecture time of 50 to 100 hours per item. Items 7 and 8 are more marginal but also important. Students should be expected to have already acquired elements of quantum mechanics and relativity and a solid enough knowledge of mathematics (preparatory classes could be organised by and in universities). A total of 500 hours would mean a full year.

1. Basic nuclear physics: scattering from a potential, spin and isotopic spin, energy levels, optical model, shell model, cluster model, collective models, nuclear shapes, rotation and oscillations, notions of mean field, nuclear reactions, α, β and γ radioactivity, nuclear chart, fission, fusion.
2. Basic atomic physics: interaction of charged particles and γ rays with matter, ionization energy losses, radiation energy losses, electromagnetic and hadronic showers, biological effects of radiations, radiation detection, basics of radiation protection and shielding.
3. Basic neutronics: introduction to nuclear reactors, neutron cross-sections, neutron slowing down and thermalization, neutron transport, simulations and lattice calculations.
4. Reactor concepts and designs: moderators, fuel cycle, criticality, fluid dynamics, Zero-power reactors, light and heavy water reactors, pressurized water VVER reactors, brief introduction to Generation IV reactors (fast: IFR, GFR, SFR, LFR and thermal: VHTR, SCWR and MSR) and to breeders.
5. Uranium ore: mining, enrichment, isotope separation, extraction from oceans, fabrication of the fuel and front end of the fuel cycle. Storage of spent fuel, treatment and storage of nuclear wastes, decommissioning, problems of proliferation.
6. Nuclear safety, individual and environmental protection, case studies (Three Mile island, Chernobyl, Fukushima, etc.), deterministic and probabilistic safety algorithms, education of the public, regulations, protection against terrorist attacks.
7. Other nuclear applications: medicine, chemistry, astrophysics, dating, material sciences, nuclear weapons, etc...
8. Nuclear power in the world, basics of geopolitics, trends in the various continents with particular emphasis on Asia.

NUCLEAR PHYSICS, PARTICLE PHYSICS AND ASTROPHYSICS: WHICH CHOICE FOR VIET NAM?[15]

The recent holding of a conference in Buon Ma Thuot, covering three major fields of contemporary physics, nuclear physics, particle physics and astrophysics, is a good opportunity to ask how much effort Viêt Nam can afford to devote to each. Ideally, we would like to be able to answer that such a question is out of place, that we must obviously spend resources on each of these fields and on fundamental research in general, a prerequisite for good universities and successful applied research,

[15] Published in Tia Sang.

R&D and industry. However, the real world in which we live is very far from such ideal. The constraints imposed on fundamental research require the enforcement of a very rigorous scientific policy aimed at making optimal use of the limited resources that the country can afford to devote to fundamental science. This simple fact motivates the present comments, which, however, have no pretension at contributing much wisdom but are simply meant to trigger discussion.

A few general remarks

Physics is the result of a constant dialogue between theory on one side and experimentation and observation on the other. They feed each other, the progress of each being fuelled by the achievements of the other. It is a common disease of less developed countries to ignore this fact and teach their students that they should become theorists if they are bright, experimenters otherwise. Fifteen years of being in close contact with Vietnamese students have shown me that the country does not make exception to the rule. It is bad practice, not so much for the selection which it implies – which turns out fortunately to be nearly irrelevant – than for the wrong idea that it imprints in the brain of young students of what physics really is.

We must avoid training students, either at home or abroad, in fields that are not given proper support at home. A better way to say the same thing: we must give proper support to fields in which we choose to train students. Not doing so is irresponsible: it is wasting their skills and talents. Proper support means supporting teams that exceed some critical mass and giving them means to compete on the international scene. Praising team work does not mean at all depreciating individual achievements. The recent awards of the Ta Quang Buu Prize are a bright illustration of such successes. But a scientific policy can not pretend making clever individuals, indeed it is not its role; it can only help them doing the best of their talents. We need to support teams that exceed the critical mass beyond which a sustainable effort becomes possible.

Which criteria should we use to select such teams? as physicists, we must have a judgment of the chances of the fields in which they work to bear fruits on a reasonably short time scale at the frontiers of present knowledge. Physics keeps evolving, domains that were in the forefront a few decades ago may have lost much of their interest today. A more practical criterion is the presence in the country of team(s) having the competence and motivation to succeed and having the potential to become the seed for a successful presence on the international scene. Other arguments that have some weight in the decision are a realistic assessment of the means required on a long range in terms of financial and manpower resources and of the training opportunities offered by the field with respect to the needs of the country in applied research, R&D and development of its industry.

The amount of resources that need to be devoted to experimental physics in each of the three fields deserves some comments. They are part of what one calls big science and make exclusive use for their research of expensive equipment that is operated and maintained on an international scale. Supporting those implies, in priority, making it possible for their teams to use major international facilities which Viêt Nam cannot afford to have at home (e.g. LHC, VLA, RIKEN, etc). In addition they need some cheap and simple tools at home that are good for training (e.g. small radio telescope, radiation analysis and spectrometry instruments, cosmic ray detectors, etc) but the resources devoted to such instruments can and must be kept to a minimum. We need to invest in brains, not in instruments. Decisions to buy expensive equipment should never be taken top-down but be in response to pressing and justified bottom-up requests.

For both experimental and theoretical physics, adequate computing means must be accessible. Here again, it does not necessarily mean having them at home. There exist today many opportunities to make use of large computing and data handling networks that are managed at international level.

Nuclear physics

Nuclear structure theory has its tool, Hartree-Fock-Bogolioubov mean field and quasi-particles, since the early sixties and its theory, QCD, since the late seventies. Yet, nuclear physics has still a place in

the foreground of contemporary science for at least three reasons: one is the central role played by nuclear physics in modern astrophysics, in particular in the description of supernovae collapses, another is the revival given to experimental nuclear structure studies with the availability of radioactive beams giving access to studies of nuclei far from stability. The third reason, possibly the most important, is the need to train nuclear physicists in a world where nuclear applications are ubiquitous, whether in industry, medicine and biology, material sciences, military applications and energy production.

The latter is particularly important in Viêt Nam, now committed to the construction of nuclear power plants in Ninh Thuân in the frame of agreements signed with Russia and Japan. As is well known, and repeatedly declared by competent Vietnamese scientists having experience with the Da Lat reactor, we are unprepared for the event and, for now fifteen years, we have proven unable to train the team of engineers and scientists required for the task. It has already caused a six year delay to the project, a huge waste of money. The United States had Argonne and Oak Ridge, Soviet Union had Obninsk, the United Kingdom had Harwell, France had Saclay, we have no institute centralizing the effort. The United States had Fermi and Walter Zinn, Soviet Union had Kurchatov, the United Kingdom had Cockcroft, France had Joliot-Curie, we have a committee but no one in charge. We, as scientists, must feel responsible for the success of the project. The day the Government and the population will realize that Viêt Nam is loosing its independence in terms of energy or the day there will be a major nuclear accident, they will rightly turn to us and blame us for not having prevented it when we could have done it. It is time to make the Government conscious of the pressing need to change style. At the occasion of the celebration of the 30th anniversary of the Da Lat research institute, in the name of the Minister of Sciences and Technologies, his deputy Lê Dinh Tiên praised the Da Lat Nuclear Research Institute for its achievements during the past thirty years and for the asset represented by its staff *"in view of a successful implementation of the nuclear power development program"*. He added that *"in order to implement it the Ministry has been given the important task to establish a large Centre aimed at enhancing the national nuclear infrastructure [...] and at training a staff having the ability [...] to build, operate and maintain safely and efficiently nuclear power plants."* He concluded by asking the Vietnamese nuclear community *"to devote more manpower, brainpower and time [...] to speeding up the implementation of the project"*. It is clear that the Government, starting from the level of the Prime Minister, expects the nuclear physics community to play a major role in this endeavour. It would be irresponsible to be deaf to such a message.

Particle physics

We are still under the excitement of the discovery of the Higgs particle, two years ago. It was the triumphal reward of nearly thirty years of effort to search for the last missing piece of the Standard Model. However, a frightening scenario is threatening us, which we all hope will not materialize: one in which no other major discovery would be accessible to LHC. For now more than three decades, experimental particle physics has kept confirming the predictions of the Standard Model with always better accuracy without finding hints of what happens beyond it. In particular, no evidence has been found for the existence of supersymmetric partners of known particles in spite of the extreme beauty and attractiveness of SUSY. The future of experimental particle physics would look very gloomy, by lack of arguments setting a scale for future explorations (other than the GUT/Planck scale!), if no sign of new physics could be revealed at LHC. It would make the case for a new (linear) accelerator very weak, at strong variance with the cases of LEP and LHC, each of which enjoyed extremely strong and convincing arguments for the defence of its proposal.

For Viêt Nam to contribute efficiently to experimental particle physics, it needs building a team with proper expertise. Today, it is very far from it by lack of adequate support. It is time to decide whether we wish or not to support experimental particle physics in the country. If yes, we should give it proper support. If no, we should stop sending students abroad to be trained in a field for which there is no future in Viêt Nam.

Astrophysics

Astrophysics is by far the most dynamic of the three fields. Three decades ago, many astrophysicists did not believe in black holes! We now know that there is one at the centre of essentially each large galaxy. High precision studies of the Cosmic Microwave Background observe the Universe only half a megayear after the Big Bang and also learn about the re-ionization period when the first stars and galaxies formed. Observation of high redshift galaxies (up to z=10!) brings detailed information on the early formation of structures in the Universe. Recent BICEP2 polarization results even suggest effects of gravitational waves related to inflation! Spectacular progress has been made in the understanding of how stars form, live and die.

Astrophysics is the domain of three of the most puzzling questions of contemporary physics, dark energy, inflation and dark matter. The park of observatories at all wave lengths, both ground based and in space, keeps growing and improving performance in terms of both sensitivity and angular resolution. In East Asia, Japan, with a very rich ground and space programme, China, in particular with the construction of a giant radio antenna not far from Ha Noi, Korea and Taiwan play a major role. Access to data from all large observatories is possible by association with international collaborations.

Expertise exists in Viêt Nam in radio astronomy (legacy of Nguyen Quang Rieu), at Hô Chi Minh City and Ha Noi. The development of space applications, with important resources allocated to the Viêt Nam National Satellite Centre, in particular for the observation of the Earth, is the sign that the Government means to strongly support this effort.

Summary

Given the limited resources available for fundamental research in the country, we should consider it our duty to select the topics on which to work with extreme care. In particular we should make sure that students are trained on topics that are likely to receive significant support in order not to waste talents and skills. A better balance between theory and experiment/observation must become a priority in order to progress. A few arguments of likely relevance have been tentatively presented. They have no pretension to carry special wisdom but are simply meant to provoke discussion and, hopefully, action in the near future. Vietnamese outstanding competences exist abroad, they should be invited to contribute to such discussions.

CERN IS CELEBRATING SIXTY YEARS OF EXISTENCE[16]

Having spent well over thirty years of my life at CERN, I have been asked by several friends, on the occasion of the celebration this year of the 60th anniversary of the organization, to share with them memories of these happy days. It has indeed been an outstandingly good fortune to live through all these years in such an environment. I got so much from CERN and gave it so little in return that I can praise its excellence without fearing to appear pretentious.

The first evidence that comes to my mind when I remember CERN is the outstanding quality of the people whom I met there; whether students, Nobel laureates, engineers or administrators, they shared a same intellectual and moral rigour, a same dedication to the success of the Organization, a same love for science.

In the eighties, I had the good fortune to take part in one of the most successful CERN experiments, which led to the discovery of the weak bosons and of hadronic jets revealing parton substructures in protons. In this endeavour, we were joined by some of the best students and young postdocs around the world. It was a moving reward, on July 4th 2012, to watch two of them, Fabiola Gianotti and Joe Incandela, then spokespersons of the ATLAS and CMS experiments, reporting on the discovery of the Higgs boson at the Large Hadron Collider.

I also had the good fortune to work in close contact with future Nobel laureates, such as Carlo Rubbia, Jack Steinberger, Burton Richter, Georges Charpak and to be friend with many others such as Jim Cronin,

[16] Published in Tia Sang, 2014

Leon Lederman, Tiny Veltman, Martin Perl or Sam Ting. Such familiarity was extremely enriching, not only by the obvious benefit of working close to them, but also by the demystification it implies. What I mean, is that people who did not have such good fortune tend to see them as disembodied genii. Nothing is more sterilizing for young students. It makes them think that there is something so special about such genii, that it is out of question for them to once enter their club. But when you work close to them, you see that they are people like you and me, except that they are possibly more rigorous, more determined to have success, more dedicated to their work, more eager to decipher Nature and more willing to work hard. Far from being icons, they become examples to follow and it is having more respect for them to see them as such than as inaccessible genii. To make a discovery that impacts the history of physics implies some good fortune, of course, but what makes them different is simply that they do not miss the chance when it happens. They do not sweep under the carpet the little mismatches that they may have noticed between their observations and what they expected to find, but fight them through merciless until they unveil their secret.

Excellence also among the many friends and colleagues with whom I worked, coming from all around the world. Working in an international environment makes you become somewhat of a citizen of the world. When I was a student, the motto of my university was "For Homeland, Sciences and Glory". It did not take me long to find some futility in glory; we should not fight for glory, but for more noble goals, such as justice, freedom or excellence; glory will come as a bonus with success, free of charge, but it should not be an aim in itself. Living at CERN, Homeland also became less evident as a primary goal; I count among my best friends, with whom I have been working side by side, German colleagues, against whom we were in war when I was a child and against whom my grand fathers had lost their life in the war that preceded. Such experience teaches us that our real homeland is the Earth, not such or such a country. Of course, when the Earth wins, so do the countries which it is made of. When I was at CERN, globalization was not as obvious as it has now become; our idea of supranationality was rather at the scale of Europe. The founding fathers of CERN were strong believers in a unified Europe and we were sharing their dream. We were not thinking in terms of what can Europe do for us, as European countries mostly think today, but in terms of what can we do for Europe, taking it as granted that whatever might be good for Europe would automatically be good for us. Loving one's nation is of course worth of praise, as is loving one's region, one's village, one's family; these are the communities who built up for us, often at the price of blood and tears, the framework in which we can live a happy life. But such love should not imply hating the neighbour nation, the neighbour village, the neighbour family. When it does, it leads to an exacerbated nationalism which is prompt to write the darkest pages of the history of mankind.

Another major asset of CERN was the proximity between different professions, teaching each of us to respect each other, whether physicists, engineers or administrators. As an experimentalist, I was very close to theorists, such as Maurice Jacob, Jacques Prentki, John Ellis. Whenever I might have a question, I would not hesitate to drop by their office and the CERN cafeteria was well known for being a melting pot of all kinds of skills and talents. The "machine physicists", as we called them, namely those in charge of the design, construction, operation and maintenance of accelerators, were a particularly remarkable family of outstanding talents, with people like Simon van der Meer or John Adams.

A virtue of CERN, which I did not meet anywhere else in my life, was the quality of the administration. CERN, being a young organization, had had no time yet to build up bureaucracy with the set of paralysing rules that characterize old societies. The administrative staff was small but excellent. We had a document, called "Staff Rules and Regulations", which did not exceed hundred pages or so. Things worked superbly because the administrators, whether in the finance or personnel divisions (we did not talk about "human resources" at that time) were working in a pure spirit of service. They were not applying blindly a set of rules, as robots would have done, but they had sufficiently well absorbed their spirit to make an intelligent use of them. It is remarkable that it is often the best people who want to serve the community and the most mediocre who prefer to display their power and authority in behaving as petty tyrants.

For seven years, I served as director of research in the CERN directorate, and I can bear witness of the exclusive spirit of service that was driving us. One of my duty was to attend the Council sessions;

Council, in which each country is having two delegates, a scientist and an administrator, is presiding to the destiny of the Organisation. Attending its sessions was another opportunity to meet excellent people, often scientists or diplomats, moved by only one goal: help research to progress. Good administrators of science are those who work in this spirit, which does not mean favouring science unjustly over other human activities, but considering knowledge as a noble goal worth fighting for.

These were indeed happy days. Of the three words that made the motto of my university, Science is undoubtedly that to which we were devoting our life, time and effort. During my stay at CERN, particle physics went through a major revolution with the birth of the so called Standard Model. Scientists of my generation are very fortunate to have witnessed such amazing progress in our understanding of nature, in phase with our own scientific life. It is remarkable that this has not only been the case in particle physics but also, and maybe to an even greater extent, in astrophysics and life sciences. While many questions remain unanswered in each of these three fields, none can be put aside any longer as being a mystery inaccessible to science. Our vision of the world has changed dramatically. Having had an opportunity to contribute to this progress, however modest our contribution may have been, is very good fortune. May science be smiling to the next generations as kindly as it did to us.

PLEA FOR A NATIONAL TRAINING NUCLEAR CENTRE[17]

The recent Da Nang Conference on Nuclear Science and Technology was an opportunity to measure the progress accomplished during the past two years. Important achievements were reported, such as recent advances in the diagnosis and treatment of cancer at Bach Mai hospital, by Professor Mai Trong Khoa, or progress in the description of the excited Hoyle state in ^{12}C, by Professor Dao Tien Khoa. Most remarkable was the contribution of the young generation, with a host of excellent presentations in the domain of nuclear applications, in particular nuclear reactors.

The need for Viet Nam to adopt a new safety culture was underlined in several occasions. The recent press offers reports of unfortunate events in this context: in May, we learned that Vietnam's infrastructure for nuclear safety and security (Ninh Thuan I) had failed to meet requirements and standards set by the International Atomic Energy Agency and other international treaties to which Vietnam is a signatory; in April, in the wake of losses of two high activity radioactive sources, we heard statements by Professor Tran Thanh Minh and Vuong Huu Tan, director of VARANS, saying that this is a clear indication of poor awareness and management of such dangerous material and that inspections of radioactive material are conducted every three years instead of yearly as they should because VARANS is short of manpower and equipment; in July we learned that Prime Minister Nguyen Tan Dung had approved a new decree on increased security measures to manage and control radioactive devices in the country, pointing out many shortcomings and limitations within the current system, which led to numerous cases of radioactive devices and equipment going missing in recent years.

In a different vein, we also learned from the recent press, on the occasion of a seminar on nuclear human resources held in Da Lat on July 17th, that the lack of young experts in the nuclear energy sector is a great challenge to nuclear research and nuclear energy development in Vietnam. Participants at the seminar said that experts in the field are getting old while there are few young talented scientists. The Director of Da Lat Nuclear Research Institute's training centre, Nguyen Xuan Hai, said that six universities offer training courses in nuclear-related fields with about 200 graduate students each year, but low job offer and low salary make research establishments not attractive to young talents.

Moreover, I should like to add, the training provided by these universities is usually inadequate. As an example, the syllabus of the master courses delivered by the Ha Noi University of Sciences devotes 29% of the time to teaching English and a little bit of Mac-Le against only 26% to nuclear physics, the rest being on issues such as math for physics, statistics, computer simulation, signal processing, etc. I do not think that a master on nuclear physics is the place where to teach English. Moreover, the topics being

[17] Published in Tia Sang

taught in nuclear physics are far from matching the needs of the nation but resemble those, which I was taught 55 years ago, at a time when we were learning nuclear physics in order to understand the nuclear force. In particular, not a single word is said on nuclear reactors and I know of several examples of young Vietnamese having a master degree in nuclear physics and not knowing how a reactor works.

I argued, in my presentation, that the reasons for which we study nuclear physics today are very different from what they were in the fifties and, consequently, the training that we must provide is also very different. The key to the strong force, quantum chromodynamics, was found in 1973 by particle physics, depriving nuclear physics of one of its main missions. Yet, there are still two good science reasons to study it today, and many practical reasons. The science reasons include radioactive ion beams and nuclear astrophysics. The former have caused a renaissance of experimental nuclear physics. They explore the nuclear equation of state far from stability, discovering new isotopes and new forms of dynamics, such as halo nuclei. They contribute essential data to nuclear astrophysics. They have new applications in medicine and industry. They enjoy strong support all around the world; in Asia, Japan is a leader and Korea and China are joining the club. Concerning the latter, nuclear processes are ubiquitous in astrophysics: Big Bang nucleosynthesis and stellar evolution. Understanding what is going on requires knowledge from laboratory measurements. At the same time astrophysics offers nuclear physics a laboratory having no equivalent on Earth.

Practical reasons to study nuclear physics cover the domains of nuclear energy and of radioactive sources. Energy consumption in Viet Nam increases by ~15% per year: the country needs nuclear energy to match such needs. Nuclear power plants are efficient, safe, CO_2 free and remain a major asset in energy policy but they require highly competent management of their operation, maintenance and exploitation and we see them today very differently from how we saw them at the end of the fifties. They generate irrational fear and have to face opposition from a politically very strong movement; the question of waste storage and treatment is still pending; cost increases in mining, in decommissioning, in safety measures are more significant than anticipated; ore reserves are finite; with increased geopolitical instability and terrorism threat, proliferation and dissemination are more serious concerns than anticipated; transfer to private industry, with the danger of financial interests becoming dominant, is not without problem. All these new facts have to be taken in due account when deciding which kind of training is required today. We want to train responsible scientists and engineers who do not accept the virtues of nuclear energy as a dogma but are able to defend them when they have solid arguments to do so and to possibly moderate them when the views of nuclear opponents are touching on points that are worth consideration.

Radioactive sources and particle accelerators pervade our modern societies. Their use spans a very broad spectrum of applications in medicine, industry, agriculture, mining and geology, archaeology, etc. They are used as tracers, as radiography sources for imaging or as radiation sources for sterilization, for killing tumours or for inducing mutations. Particle accelerators do the same job as radio nuclides do, but allow for reaching much higher intensities and energies. Synchrotron light sources reveal or modify the structure of materials, electron beams are used for machining, welding, surface treatment, etc., cyclotrons for the production of radio nuclides, ion beams for cancer therapy, analyses and implantation in semi-conductors for the electronics industry.

Viet Nam is very much behind in training scientists, engineers and technicians in nuclear science and technology. Catching up with what is needed for the country to develop and progress is urgent. Top priorities must be given to training scientists, engineers and technicians for a responsible and sustainable management of the NPP programme (construction, operation, maintenance and exploitation) and of nuclear applications to medicine and industry, including particle accelerators. As was said earlier, particular attention must be given to matters of safety.

Issues to be taught include: Basic nuclear and atomic physics; Biological effects of radiation and radiation protection; Basic neutronics, thermalization and transport; Reactor concepts and design, moderators, fuel cycle, criticality, different types of reactors, introduction to Generation IV and breeders; Uranium ore, mining, separation, enrichment, front end of the fuel cycle; Storage of spent fuel, storage and treatment of wastes, decommissioning; Nuclear safety, individual and environmental protection,

education of the public, regulations; Radio-nuclides, applications to medicine and industry, safety and control; Particle accelerators, basic acceleration methods and technology, use in medicine and industry; Nuclear weapons, non-proliferation, nuclear security; The nuclear world, IAEA, Greens, dissemination, Asian geopolitics.

Today, universities lack the teaching workforce having the required competence in many of the issues to be addressed. A national centralized training effort is therefore mandatory, bringing together existing skills from both inside and outside the country. It seems to me that we are spreading our resources, money and talents, over many too many ministries and institutions. This was illustrated at the conference by the report of Professor Vuong Huu Tan on the use made of the resources allocated to Research Program KC05/11-15.

I think that the time has come to unify the presently scattered landscape in the domain of training and to create a National Training Nuclear Centre with a single person at its head in order to have a single, coherent and common approach to Human Resource Development. Many students are being sent abroad to study, in Russia, Japan, Hungary, etc..., but there is no place to welcome them back home. If there were such a place, it would make it possible to organize in a coherent way the follow up of their training abroad. The students could share their experiences, teach each other, in a word build up a team culture with skills largely exceeding the sum of the skills of the team members.

It would cost very little money to create such a Centre, it does not need expensive instruments to start with. The Da Lat reactor should be used extensively for training purpose. Simulators exist across the country. One should start by collecting people rather than by investing in expensive equipment. As I often say, we must invest in brains, not in instruments. In the future, of course, one can think of a research reactor of higher power than the Da Lat reactor, more simulators, etc... but this is not today's priority.

I do not mean that all the students who have been trained abroad should be permanently hosted in the Centre. Some may, on a yearly or so basis, others would spend there the time of a course, either as student or as lecturer or as member of a working group, etc... One should take the opportunity of the existence of such a Centre to send less students to study abroad and to invite more foreign lecturers to lecture at the Centre.

The presence of a single person at the head of such a Centre, with direct access to the Prime Minister, would mean considerable progress with respect to the present situation. The Government would be able this way to listen to a single voice, speaking across the many
Ministries involved, and to be better informed in order to make up their opinion and take decisions. One might even hope that the Centre be a first step toward a better centralization of the whole nuclear programme.

The central position of the Centre would make it easier to use existing facilities. One such example is the use of the pelletron, a particle accelerator owned by the nuclear physics department of HUS, for material science studies of radiation damage on reactor material, a
topic addressed by HUST in collaboration with a Japanese university. Breaking the walls between various institutions is badly needed in the country, and the Centre would give an opportunity to do so.

The competence and experience acquired with thirty years of successful operation of the Da Lat reactor must be made optimal use of.

The Vietnamese nuclear physics community needs to stick together to make the best of this national effort and to warrant coherence and effectiveness in its action. Administrative barriers between institutions, ministries, etc… must be removed in order to foster common training initiatives.

We, engineers and scientists who happen to know some nuclear physics, cannot pretend that these problems do not concern us. The public and the government expect us to be concerned. It would be irresponsible to ignore it. If we want our voice to be heard, we have to speak up as a community.

2015 NOBEL PRIZE REWARDS NEUTRINOS[18]

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Once again, neutrinos have been invited to Stockholm, it has become a habit. Since the end of the eighties, each decade has seen the award of a Nobel Prize to neutrino physics. The father of neutrinos, Wolfgang Pauli, is also a Nobel laureate but he earned his prize for something else: the exclusion principle. As the main property of neutrinos is their extremely weak interaction with matter, they are very difficult to detect. Most of the low energy neutrinos produced by the Sun traverse the Earth without being affected, each second forty billions of them per square centimeter! As a result, paradoxically, the presence of a neutrino is often inferred from its absence among the detected products of an interaction: something is missing in the balance sheet of energy. This is the case in beta decay and was a puzzle in the thirties. While Niels Bohr was suggesting that energy conservation might be violated, Pauli pleaded for the emission of an undetected neutral particle, he called it a neutron. What we call today a neutron was discovered by James Chadwick in 1932, and a proper description of beta decay was given by Enrico Fermi in 1934: Pauli's particle took then the name of neutrino, meaning small neutron in Italian. By then Pauli had convinced the scientific community of the reality of his baby.

Over the years, neutrinos, or equivalently anti-neutrinos, have continued to be detected and identified by their absence: such has been and still is the case at the high energy colliders, such as the Large Hadron Collider (LHC) in Geneva. In particular, they provide a convenient signature for the detection of the very massive charged weak bosons, $W^{\pm}$, which decay instantaneously into a charged lepton, say an electron, and a high energy neutrino – meaning a large deficit in the energy balance sheet. In parallel with such experiments, others decided to take the bull by the horns and to assemble large detectors that would oppose sufficient matter to the neutrinos on their trajectory for having a small fraction of them interact.

The first successful experiment of this kind was performed in 1956 by Clyde Cowan and Frederick Reines using a nuclear reactor as a source of anti-neutrinos, with a flux in excess of 10^{13} per second per square centimetre. They detected the anti-neutrinos from their interaction with protons, producing a positron and a neutron. This is equivalent to neutron beta decay where the final state is a proton, a neutrino and an anti-neutrino, both of the electron type. For this reason it is called inverse beta decay. The protons were those of the water molecules contained in two tanks of about 200 liters each, with cadmium chloride dissolved in them. The positron was identified by the coincidence of two 511 keV gamma rays, emitted when it annihilated instantaneously with an electron and detected in liquid scintillator counters. The neutron was detected by its delayed capture from cadmium signaled by the emission of another gamma ray. The signal, a pair of 511 keV gamma rays followed a few microseconds later by another gamma ray, was observed at a rate of about three per hour and found to disappear when the reactor was switched off. Frederick Reines was awarded the Nobel Prize in 1995 but Clyde Cowan had died twenty-one years earlier.

Cowan and Reines started a long lineage of experiments using as neutrino sources either nuclear reactors at low energy or particle accelerators at high energy. The former are electron neutrinos, the latter are dominated by muon neutrinos from meson decays but include as well electron neutrinos and, when the energy is high enough, tau neutrinos. Detectors were either heavy liquid bubble chambers filled with freon or propane or assemblies of iron plates, used to give a chance to neutrinos to interact, followed by electronic particle detectors, used to produce a signal when such an interaction had occurred. Their legacy in shaping up the modern theory of particle physics, called the Standard Model, is enormous. Without embarking into a detailed description of its substance, it is necessary to summarize some of its main features in order to understand the experiments that have been awarded the 2015 Nobel Prize.

We start with a simplified version of the Standard Model with all elementary particles being massless; it is not such a bad approximation since all known elementary particles have masses that are less than 10^{-17} times the only mass scale in the theory, the so-called Planck mass. Moreover, the Standard Model ignores gravitation, which has indeed negligible effects at the scale of typical particle physics experiments. Indeed, the incompatibility between quantum physics and gravitation at the scale where they

meet is one of the two main puzzles of contemporary physics (the other being the nature of dark energy). It requires the conception of a new theory.

In such a simplified model, we have fermions, which are particles making up matter, obeying Pauli's exclusion principle because they have spin one-half. The electron is one of them. We also have bosons, which behave more like light, allowed to occupy a same quantum state because they have spin one. There are three such bosons, one associated with each type of interaction: the photon is associated with the electromagnetic interaction, the weak boson is associated with the weak interaction, such as beta decay, and the gluon is associated with the strong interaction, responsible in particular for the nuclear force. The fermions come in two categories, leptons and quarks. Protons and neutrons are made of quarks. The leptons have no strong interactions, only weak and electromagnetic interactions. The neutrino, being a neutral lepton, has no electromagnetic interactions either, it has only weak interactions. Both quarks and leptons come in three pairs. In the case of leptons, which are of interest here, these pairs include a charged particle and a neutrino. The charged lepton of the lightest pair is the electron, then comes the muon, then comes the tau. Each of their associated neutrinos has been identified as such in neutrino experiments, the direct detection of the muon neutrino having been awarded the 1988 Nobel Prize (Leon Lederman, Mel Schwartz and Jack Steinberger).

The Standard Model describes interactions between particles as a coupling between fermions and vector bosons. The electromagnetic interaction couples a photon to a pair made of a charged particle and its anti-particle, such as an electron-positron pair, which can also be seen as the charged particle emitting or absorbing a photon. Similarly, the weak interaction couples the weak boson to a lepton pair. As the real weak boson is very massive, at variance with the massless photon, the weak interaction at low energies is very much weaker than the electromagnetic interaction. A first complication arises from the fact that the weak boson W may be charged or neutral. Hence four possible couplings: $W^- \leftrightarrow e^- \nu^*$, $W^+ \leftrightarrow e^+ \nu$, $W^0 \leftrightarrow e^- e^+$ and $W^0 \leftrightarrow \nu \nu^*$ where e^- and e^+ stand for electron and positron, ν and ν^* for neutrino and antineutrino, both of the electron family. One speaks of charged currents in the first two cases, of neutral currents in the latter two. Another difference between electromagnetic and weak interactions is that the latter are restricted to left-handed leptons and right handed anti-leptons, where right-handed means with spin pointing in the direction of motion and left-handed with spin pointing backward. Note that massless particles travel at light velocity and cannot be brought to rest: our definition of handedness is therefore making sense.

A particularity of neutrinos is already apparent at this stage: a right-handed massless neutrino would have no interaction of any kind, one says that it would be "sterile" and would therefore be a purely abstract concept having no physical reality: no experiment could be conceived to give evidence for its existence. Also, it has been clear for many years that if neutrinos have a mass, it must be a very small mass, an "abnormally" small mass one would like to say although it is difficult to define what we mean by "abnormal" when we do not understand in detail how fermions acquire a mass. We only know that it is related with the breaking of a primordial symmetry that splits the photon from the weak boson (they would have been a same particle if the symmetry were not broken) and that it implies the existence of one or several spin 0 bosons, called Higgs bosons. The recent discovery of the lightest of these, possibly unique, has given a spectacular confirmation of the idea but the details of how it works for fermions are still unclear. In addition to acquiring a mass, fermions also get mixed between the three families: they are in different quantum states when they propagate freely – as mass eigenstates – and when they interact weakly – as family eigenstates – a mixing that can be described by the four angles of what is called the Cabibbo-Kobayashi-Maskawa (CKM) matrix. In the case of the three pairs of quarks, which are much more massive than leptons, the quark masses and the four mixing angles have all been measured. The question then arises: does the same happen for leptons? Can we measure a CKM matrix for leptons?

Of utmost relevance to such questions are experiments aimed at detecting neutrinos produced from the nuclear fusion taking place in the Sun. The first of these, conducted by Ray Davis deep into the Homestake gold mine, was continuously operated between the end of the sixties and the middle of the

nineties. The detector was a 400 m^3 tank of perchloroethylene, the idea being that a tiny fraction of the solar neutrinos crossing the tank would be captured by a chlorine atom and turn it into an argon atom. The gaseous argon was periodically collected by bubbling helium into the tank. From its early years of operation, the experiment consistently detected only one third of the expected amount of solar neutrinos. For many years the scientific community suspected a flaw in the experimental method, then in the solar model used to predict the neutrino flux. With time, however, and with new experiments confirming Davis'result, it was finally recognized that solar neutrinos were simply disappearing between the Sun and the Earth: the Homestake experiment was first to observe the effect of neutrino oscillations.

What happens is that neutrinos are always produced in weak interactions in a state of a well defined family, electron, muon or tau. However, CKM mixing implies that such states are in fact coherent superpositions of states of different masses. As the neutrino propagates freely, each of these mass eigenstates are plane waves of frequencies proportional to the neutrino energies, therefore different when the neutrino rest masses are themselves different. This generates interferences between the three mass eigenstates and therefore progressive appearance of new families different from the original family (if compatible with energy conservation) and progressive disappearance of the original family.

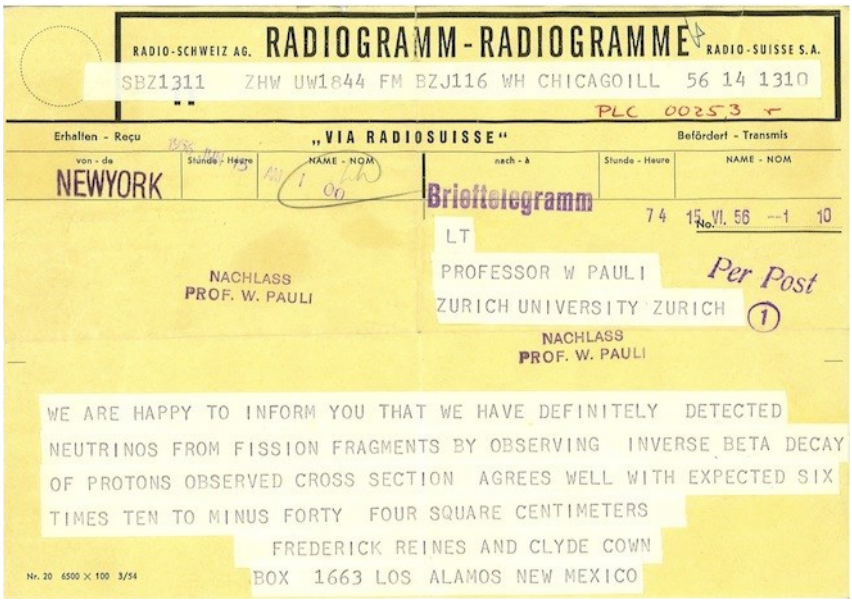
Among the experiments that confirmed Davis' result are large neutrino detectors located in Japan and Canada. The first underground Japanese detector, called Kamiokande, aimed at detecting proton decays. It did not detect any but identified many solar neutrino interactions, from electron neutrinos, as well as atmospheric neutrino interactions from muon neutrinos. Atmospheric neutrinos are from large air showers produced by galactic cosmic protons interacting with the Earth atmosphere; they contain many pi mesons that decay into a muon and its companion neutrino. Moreover, Kamiokande had the good fortune to be in operation when the 1987 major supernova collapse took place and it detected a burst of neutrinos from the explosion. Masatoshi Koshiba, the father of Kamiokande and Ray Davis shared one half of the 2002 Nobel Prize.

When it became clear that the effect of neutrino oscillations could be detected, a new experiment, called Super-Kamiokande, was designed and constructed; "nde" at the end of its name no longer means "nucleon decay" experiment but "neutrino detection" experiment. Located 1 km underground, it is a gigantic cylindrical water Cherenkov detector, forty meter high and as much in diameter, seen by over thirteen thousand large photomultiplier tubes. The outer layer is optically separated from the core. Super Kamiokande obtained remarkable solar neutrino results, being in particular able to identify elastic neutrino-electron scattering, making it possible to point back to the Sun with excellent precision; it provided evidence for muon neutrino oscillations from the up-down asymmetry of detected muon neutrinos; it confirmed this result by detecting muon neutrinos from a neutrino beam produced 300 km away.

The Canadian detector, called Sudbury Neutrino Observatory (SNO), was also an underground water Cherenkov detector, at a depth of 2km but of smaller size than Super-Kamiokande, spherical in shape and filled with thousand tons of heavy water. Operated over the first six years of the new millennium, it recorded solar neutrinos separately from their neutral current and charged current interactions on deuterons. It also detected neutrino-electron elastic scattering events, but in much smaller quantity than Super-Kamiokande. While Super-Kamiokande muon neutrino data are mostly exploring muon-tau neutrino oscillations, SNO data are mostly exploring electron-muon neutrino oscillations. Together, they provided clear evidence for massive neutrinos. For these remarkable achievements, Takaaki Kajita for Super-Kamiokande and Arthur McDonald for SNO have been awarded the 2015 Nobel Prize for physics.

The present experimental situation was recently superbly summarized by Guido Altarelli (arXiv:1404.3859v1 [hep.ph] 15 Apr 2014). One would think that the case for neutrinos being special objects requiring new physics beyond the Standard Model gets weaker now that neutrinos are known to be massive, as charged leptons and quarks are. The opposite is true: when trying to make sense of the measured mass differences and mixing angles between the three neutrino families, one finds it very difficult. The case for Majorana neutrinos, meaning that antineutrino and neutrino are a same particle, at

variance with the Dirac neutrinos of the Standard Model that differ from their anti-particles, is instead getting stronger with time. And this in spite of the failure to detect neutrinoless double beta decays, which would give direct evidence for Majorana neutrinos. Another puzzling remark: the "density" of neutrinos, calculated by taking their Compton wavelength as measure of their size, is equal to the density of the Universe, itself dominated by dark energy and the cosmological constant: is it a coincidence? Neutrinos will keep intriguing us for many more years; how long will they continue to earn a Nobel Prize in each decade?



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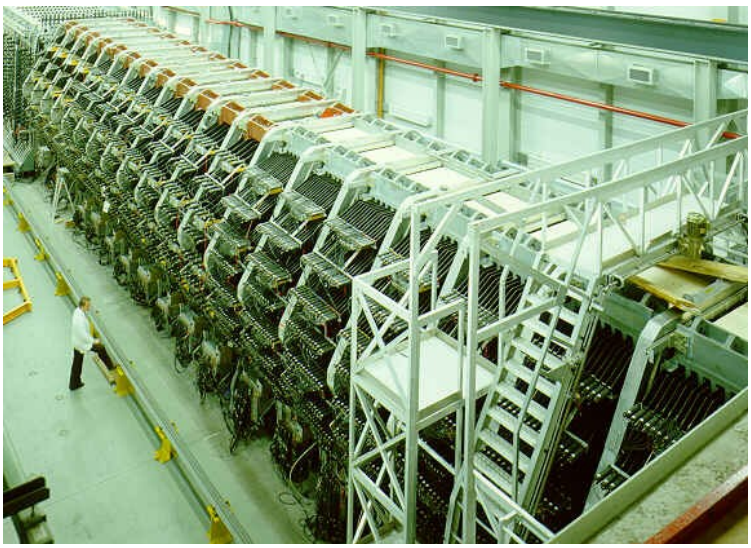
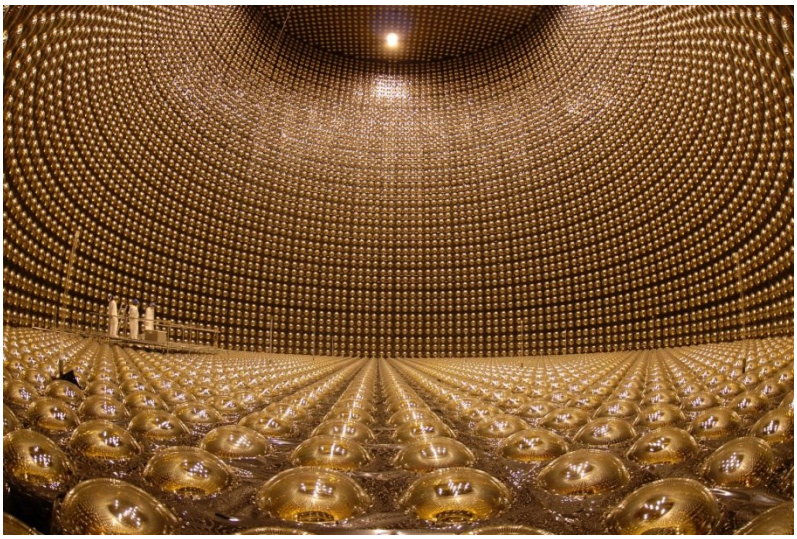
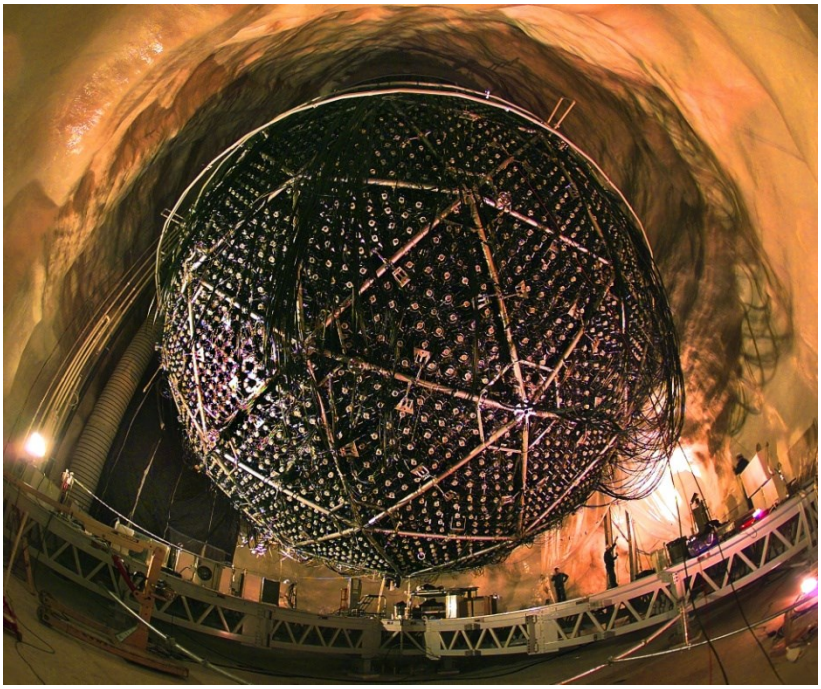
The telegram sent to Pauli by Cowan and Reines to inform him about the discovery.



The CDHS detector, surrounding the neutrino beam of the CERN Super Proton Synchrotron, took data from 1977 to 1984. It had a mass of 1250 tons and consisted of 19 magnetized iron modules interspaced with wire drift chambers.



Inside the Super Kamiokande detector before it was filled with fifty thousand tons of ultra pure water. The spherical glass domes that cover its walls are the photocathodes of photomultiplier tubes, 50 cm in diameter.



Sudbury Neutrino Observatory: the forty foot sphere is filled with thousand tons of pure heavy water.

GRAVITY, ELECTRICITY AND MAGNETISM AT THE HEART OF MODERN PHYSICS[19]

Recently, on the occasion of the recent discovery of gravitational waves, the Vietnam Academy of Sciences and Technology (VAST) organised an informal meeting. At the meeting, a question was asked by a senior physicist about the reason for gravity to be a tensor force (more precisely for the graviton to have spin 2). As no answer was given that could satisfy him, I thought that the issue might provide

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interesting material for an article in Tia Sang. The following lines aim at commenting on the rich and deep physics that is hiding behind such an apparently innocent question. I will try to use simple words that the reader can understand; my aim is not to give a lecture but simply to stimulate curiosity.

We learned in highschool that two electric charges, q and q', attract or repell each other with a Coulomb force of amplitude proportional to qq'/r^2 and that two masses, m and m', attract each other with a Newton force of amplitude proportional to mm'/r^2 where r is the distance between the two. The formal similiraity between the two laws might induce us to think (wrongly!) that both interactions are of the same nature. Indeed, they are very different as I will try to illustrate below. As much as possible, I shall ignore quantum physics and relativity and speak in terms of classical physics.

Coulomb and Newton forces are both long range forces

What is common between the Coulomb and Newton forces is their inverse proportionality to the square of the distance between two interacting point charges or point masses. This implies that the force never cancels, even at very large distances. Indeed, this is an essential feature of gravity: the gravity on Earth results from the addition of the attraction of the totality of the matter contained in the planet and is significant in spite of the very small value of the proportionality constant (Newton gravity G) that fixes the scale of the Newton force; the very large volume of the Earth compensates for the weakness of the force. But, in practice, similar situations do not occur with the Coulomb force. If we try to imagine a collection of point charges having the same charge, they would repell each other and could not be kept within a stationary volume. Of course, their assembly might be condensing to compensate the repulsion, but in this case the velocities will need to increase toward short distances and reach light velocity: relativity could no longer be ignored. Normal matter is made of both positive and negative charges, respectively nuclei and electrons. In such a collection of charges any given macroscopic volume is essentially electrically neutral and does not generate any significant force at large distances: the charges screen each other, one speaks of Debye screening. Trying to separate positive charges from negative charges in such a collection of charges is very difficult and is the basic topic being addressed by plasma physics: it is immediately counteracted by movements that tend to re-establish neutrality, producing waves within the plasma such as Alfven waves. Yet, the Coulomb force being 10^{39} times larger than the Newton force, interesting effects can be observed: an example is the Millikan experiment where one measures the effect of adding a single electron on the surface of an electrically neutral oil drop, the atoms of which contain 10^{15} or so electrons; another example is the best experimental upper limit on the photon mass, 10^{-60} g, obtained by assuming equilibrium between gravity and electromagnetic forces in the Small Magellanic Cloud.

When it comes to give a quantum description of the electric and gravity forces, the $1/r^2$ dependence translates into the fact that the particles that are exchanged in the interaction, respectively photon and graviton, must be massless. A consequence of the $1/r^2$ law is the presence of a singularity at r=0 where the force becomes infinite, which has no physical meaning: we need to refine the theory to describe what happens in such a case; I will come to this point later.

Gravity and Mach's principle

A peculiarity of gravity is that the "dynamical" mass m entering Newton's law is equal to the "inertial" mass that describes the relation between kinetic energy K and velocity v, $K=1/2\ mv^2$. This makes gravity different from other forces: in a same field, such as the Earth field, all masses fall with the same movement, whatever their value, as first clearly demonstrated by Galileo in his famous Pisa tower experiments. It invites to consider gravity as a deformation of space induced by the presence of masses rather than a force such as the Coulomb force. This approach is at the basis of general relativity and addresses an issue that has intrigued physicists for centuries: is space primordial to what it may contain or is it its content that gives it a meaning? The question, often stated simply as: *is space absolute or relative?* has been addressed by many philosophers and scientists over the past centuries, such as Democritos, Aristotle, Plato, Descartes, Leibniz, Newton, Huygens, Berkeley, Kant and Euler. Newton, observing that

a bucket at rest filled with water and a similar bucket in rotation differ in their shapes of the surface of the water, was led to the notion of absolute motion: it is the rotation with respect to absolute space which is responsible for the difference. The most famous critique of this view is due to Mach, whose analysis of the problem had a strong influence on Einstein who speaks of his work as the *Mach's Principle*. Mach insists that absolute motion and absolute space, i.e. motion and space in themselves, reside only in our minds and cannot be revealed by experience, hence they are meaningless idle metaphysical concepts and must not be used in a scientific context. All our principles of mechanics, he says, are based on our experience about relative locations and relative motions and we are not authorized to extend these principles beyond these limits. Foucault's pendulum, which keeps swinging in a plane fixed with respect to the stars, ignoring Earth's rotation, gives evidence for the relevance of a frame of reference attached to the whole Universe. The present article is not the place to elaborate further on this issue, but the reader will have grasped its deep and fundamental role in our understanding of physics. A detailed presentation can be found in the following reference: *Herbert Lichtenegger and Bahram Mashhoon, The Measurement of Gravitomagnetism: A Challenging Enterprise, ed. L. Iorio, Nova Science, New York, 2007, arXiv:physics/0407078*.

Electricity and Magnetism: a vector force

A peculiarity of the Coulomb force is that it cannot be considered in isolation from the magnetic force. A moving electric charge generates a magnetic field everywhere in space (we can observe it with a permanent magnet, such as the needle of a compass) and a magnetic field exerts a force on a moving charge. Two parallel wires in which circulate electric currents travelling in the same direction attract each other as a result of the magnetic field produced by one of the electric currents at the location of the other. It is not my intention to develop this point in too many details, but I must underline that this magnetic force is many orders of magnitude smaller than the Coulomb forces that could be expected to repell from each other the electrons moving in the two conductors; the reason is the screening which was mentioned earlier: the electric wires are made of neutral matter and the huge repulsion between negatively charged electrons in each of the two wires essentially cancels, making the magnetic force, which does not suffer such screening but is considerably smaller, appear as the dominant effect. Indeed, an elegant picture and deep understanding of the electromagnetic interaction implies describing the magnetic force as a relativistic correction to the Coulomb force, but this takes us beyond the scope of the present article. Here, it should be enough to say that electromagnetism is simply described in terms of an electric field $\boldsymbol{E}$ and a magnetic field $\boldsymbol{B}$ and that the force exerted on a charge q moving at velocity $\boldsymbol{v}$ is $\boldsymbol{F}=q(\boldsymbol{E}+\boldsymbol{v}\times\boldsymbol{B})$. The transformation of $\boldsymbol{E}$ and $\boldsymbol{B}$ under a change of reference frame is elegantly described as that of a tensor of rank 4, called the electromagnetic tensor, which itself can be written in terms of time and space derivatives of a four-vector, the electromagnetic potential, having the electric potential (a scalar) as time component and the magnetic potential (a vector) as space component. This formulation makes it possible to write the whole theory of electromagnetism (Maxwell's equations) in a remarkably simple form which makes explicit the vector nature of the interaction and consequently the spin 1 of its quantum mediator, the photon.

Gravity: a tensor force

It must already be clear to the reader that the Newton and Coulomb forces are of very different natures: all masses are positive while electric charges exist of both signs and a moving mass does not generate a field comparable to the magnetic field. Moreover, the Coulomb force is repulsive for charges having the same sign while the Newton force is attractive. There have been speculations that particles with negative masses could exist, in particular that antiparticles might be gravitationally repelled by particles. They imply developments that go well beyond the scope of the present article where they can be safely ignored: no experimental hint exists that could support them.

To better understand the nature of gravity, we need to understand how it acts on matter. As remarked earlier, we cannot restrict our analysis to an interaction between two point masses without

having to face special relativity when their velocities reach the velocity of light at short distances, not to mention the need to face quantum physics at very short distances. What we do instead, which was Einstein's approach, is to analyse what happens in a continuous medium when it is subject to gravity forces, in particular those which itself generates. It is essential to understand that in doing so, we sweep the dust under the carpet: we implicitly assume that some force, which we do not talk about, prevents matter to collapse under its own weight. We therefore accept to limit our ambitions to obtain a large distance approximation of the theory of gravity. In such a case, the forces, or stresses that are present at any point in a continuous medium can be described by a tensor T of rank 3, so-called stress-tensor, first introduced by Cauchy (see insert). The idea is that at any point in the medium the force $\boldsymbol{F}$ applied to a small surface element of normal vector $\boldsymbol{n}$ has components that depend linearly on the components of $\boldsymbol{n}$, which can be written simply as $d\boldsymbol{F}=\boldsymbol{n}.\boldsymbol{T}$ where $\boldsymbol{T}$ is a tensor having 3×3=9 components. However, as the force exerted along $\boldsymbol{n}$ is equal in amplitude and opposite in direction to the force exerted along $-\boldsymbol{n}$, this number reduces to 6. These are the three angles defining the orientation of the frame of reference in which the matrix representing the tensor is diagonal and the three stresses associated with each of the axes of this reference frame, corresponding to compressive stresses (off-diagonal elements correspond to shear stresses). In particular, in hydrostatic, these three stresses are all equal and opposite to the pressure present in the fluid.

The basic idea of general relativity, to describe gravity as a deformation of space induced by the presence of masses, requires therefore relating such deformation to the stress tensor. But we learn from differential geometry that the local deformation of space is also described by a tensor, inviting to state that the stress tensor and the deformation tensor are simply proportional to each other, which is essentially what Einstein equations are saying.

This calls for a few comments: first, we must not forget that general relativity, as stated earlier, is only a large distance approximation of the theory of gravity; second, the introduction of special relativity implies repeating the above arguments in space-time, with tensors of rank 4; third, it is customary in physics lectures to introduce general relativity after having introduced special relativity; the reason is that Einstein invented the latter before having invented the former; but I think that we are wrong to do so: the basic ideas of general relativity that I have just sketched seem to me much easier to swallow than the ideas at the basis of special relativity, which are a much stronger offense to our common sense.

I hope that the tensor nature of gravity is now clear to the reader.

Introducing relativity and quantum theory

Extending the above developments to special relativity is straightforward and, rather than making the theory more complicated, makes its expression simpler and more elegant. This is particularly true for electromagnetism; the original complications that were intriguing the pioneers of electromagnetism, such as the need to introduce retarded potentials, disappear when the theory is considered in the framework of special relativity. Electromagnetic waves, propagating at the velocity of light, appear as the mediator of the interaction between electric charges and invite the introduction of a vector (spin 1) photon when seeking for a quantum description of the theory.

In the case of gravity, the introduction of special relativity is also adding elegance to the arguments developed in the preceding section. The stress and deformation tensors are now extended to four-dimensional space-time; the former becomes the stress-energy tensor, which in the case of a fluid in equilibrium, after reduction to diagonal form, adds density as time component to the pressure describing the space components; the latter is the Ricci tensor that describes the deformation of space-time. Einstein equations are simply the expression of proportionality between these two tensors of rank 4.

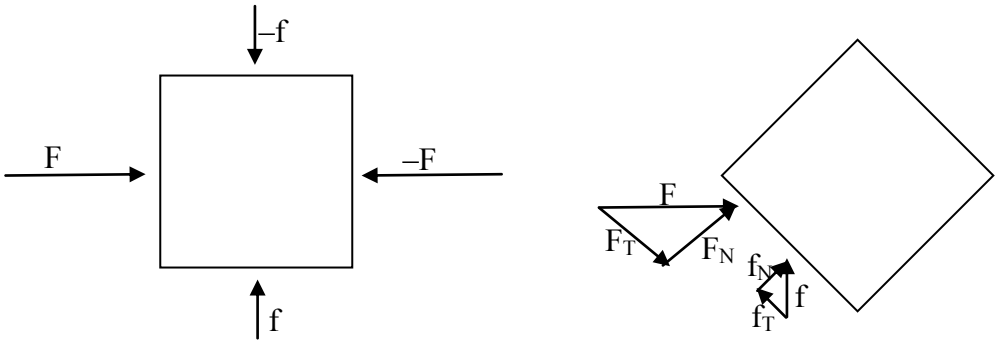
However, when it comes to the introduction of quantum effects in a theory of gravity, one meets very fundamental difficulties. Roughly speaking, Heisenberg uncertainty relations prevent the product of the mass of an object by its size to become smaller than a fixed quantity (essentially Planck's constant). Therefore, when the object becomes very small, its mass cannot become smaller than some limit and consequently so do the Newton forces within the object. At some small distance, called Planck's scale, of the order of 10^{-33} cm, Newton forces, which have to increase faster than the size decreases, will become

too large for the the size of the object, making quantum theory and gravity theory incompatible at such a scale. This is, together with the existence of what is called dark energy and which is instead a phenomenon occuring at very large distances, typically at the size of the observable Universe, the main problem of today's physics. Strictly speaking, therefore, it makes no sense to talk about a graviton, which is meant to be the particle mediating gravity in its quantum description. In practice, however, one can write an approximate theory of quantum gravity and convince oneself that the energy released in gravity interactions must be emitted in the form of waves, which one calls gravitational waves. The tensor nature of gravity implies that such waves induce tensor (quadrupole) deformations when propagating through matter, and must be associated with a spin 2 graviton in their quantum representation. Until recently, the evidence for gravitational waves was indirect: it was obtained from the measurement in 1974 of the minute progressive energy loss of binary pulsars, later rewarded by a Nobel Prize to Hulse and Taylor. Very recently, the detection of the gravitational waves emitted by the encounter of two black holes has provided the first direct observation.

Black holes

Before leaving the subject, I should like to add a few words concerning black holes. Contrary to what was said by one of the speakers at the VAST meeting mentionned earlier, their existence has no longer been controversial for nearly thirty years; on the contrary their study is a major and rich topic of contemporary astrophysics. Of course, what one observes is not the black hole itself (no light, no signal can be emitted by a black hole and reach us) but the matter spiralling around it and ultimately being swallowed by it. In particular, Sagittarius A*, the black hole at the centre of our galaxy, the Milky Way, is close enough (only 24 thousand light years) to allow for very detailed studies of its properties. When electromagnetic forces and nuclear forces are no longer strong enough to prevent the contraction of a star, which happens when the star has converted much of its hydrogen into helium, the helium core collapses under its own weight. When the original star is massive enough, the core may reach a size such that the in-fall velocity reaches the velocity of light; conversely, the escape velocity from inside the core also reaches the velocity of light, which cannot be exceeded: one speaks of a black hole. The critical size at which this happens is called the Schwarzschild radius and amounts to 5 km per solar mass. Our Sun is not massive enough to contract to such a small size and will not become a black hole. But some stars are, of which we know several examples that have been studied in detail. Such black holes, one speaks of stellar black holes, migrate toward the centre of their galaxy where they are ultimately swallowed by the supermassive black hole at its centre. Indeed, each galaxy hosts a black hole in its centre, with a mass between a million and a billion solar masses; Sagitarius A* has a mass of 3 million solar masses, which is relatively modest. Shortly after the Big Bang, when stars and galaxies started to form, the Universe, which has been steadily expanding since that time, was much denser then than it is today. Interactions between galaxies were frequent and merging of two galaxies was an important factor contributing to their growth; the role that their central black holes played in this evolution is not clearly understood and is a topic of intense study in today's astrophysics.

CAUCHY STRESS TENSOR



First consider stresses in a plate (2-D) produced by two perpendicular compressive forces F and f (left panel) onto an elementary square. What are the forces acting on a square rotated by 45^o? As shown in the right panel, they include a compressive force F_N+f_N and a shear force $F_T–f_T$. The reference square in the left panel corresponds to the privileged orientation where the shear stresses cancel. Stresses are therefore defined by three parameters: the angle defining this privileged orientation and the two compressive forces associated with it. Three is the number of parameters of a 2×2 symmetric tensor. Extension to 3-D is straightforward: we now need three angles to define the privileged orientation where the shear stresses cancel and three basic compressive forces associated with it, namely 6 parameters, the number of parameters defining a 3×3 symmetric tensor, the Cauchy stress tensor. Note that when F=f the shear stresses cancel for any orientation: this is the case of a fluid in equilibrium where a single pressure defines all stresses.

A last point concerning the density of black holes. Contrary to popular belief, it does not need to be very large; in the case of stellar black holes, it is of course; but a supermassive black hole of a billion solar masses has a size of $5\ 10^9$ kilometres and a volume $5^3\ 10^{27}$ cubic kilometers, therefore a density $5^2\ 10^{18}$ times smaller than a solar mass black hole. Indeed, supermassive black holes have very low densities and the Universe itself which has the smallest possible density (that of dark energy) has a size and a mass that obey the Schwarzscild relation. Yet it is not a black hole: beyond its Schwarzschild radius, there is more of the same rather than vacuum, as would be the case for a black hole.

I hope that the very sketchy arguments developed above will have shown how rich is the physics related to the very innocent question from which we started; as I said at the beginning, my only ambition has been to stimulate the curiosity of the reader. There exist of course a very abundant literature in which these topics are addressed; to mention just one as an example, Mendel Sach's *General relativity and matter, a spinor field theory from Fermis to light years*, published by Springer, is very much to the point.

NUCLEAR POWER TOMORROW[20]

A Chinese-French joint report on nuclear power

Recently, Chinese and French academies of sciences and of technologies have set up a common working group on nuclear power issues and presented a joint report[21] at the yearly General Assembly of the International Atomic Energy Agency (IAEA) on September 20th, 2017.

It may sound surprising to see France and China get together on such questions to the extent that, caricaturing, nuclear power belongs to the glorious past of France and aims at becoming the glorious future of China: they should not be expected to share a common vision.

More seriously, the situation of nuclear power in France[22] has significantly deteriorated in the recent past. France currently derives three quarters of its electricity from nuclear power but this share is expected to fall to one half by the mid-2020's. The main reason is the disenchantment of the general public for nuclear power, which has kept increasing over the past three decades or so, mostly after the Chernobyl incident, and has been continuously fed and enhanced by Green propaganda in most developed countries. Although irrational – a good illustration is a recent poll showing that 58% of the French

[20] Published in Tia Sang, October 2017
[21] http://www.academie-technologies.fr/blog/posts/un-rapport-franco-chinois-sur-le-nucleaire-presente-a-l-aiea
[22] http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/france.aspx

population think that nuclear power causes climate change while only 46% think that coal burning does so! – the antinuclear movement has been politically very efficient, several countries having decided to terminate the exploitation of their nuclear plants and not to build new ones. Another factor of decline has been the recent demonstration of incompetence and deceit displayed by Areva, a company dominantly government-owned present in most sectors of the nuclear cycle. It accumulated years of delay in the completion of its projects meaning a cost of over ten billion euros to the French taxpayer. The start of the French decline dates back from the emblematic Superphenix adventure, a fast-breeder reactor that met such opposition in the public that it had to be abandoned and closed in 1997 after nine billion euros had been spent on it.

China, on the contrary, is on the rise[23] and aims at nuclear power producing near ten per cent of its electricity by 2030. A strong incentive for China to limit its coal consumption has been air pollution (which has nothing to do with greenhouse carbon dioxide emission in spite of the confusion between the two kept alive by the Greens and many media). It has recently taken dramatic proportions, chronic and widespread smog in the east of the country is attributed to coal burning and the economic loss due to pollution nears 6% of GDP. China has an ambitious reactor construction programme (Figure 1). As its neighbours India and Russia, but independently, it aims at having a closed nuclear fuel cycle. While making full use of western technology it has become largely self-sufficient in reactor design and construction, as well as other aspects of the fuel cycle.

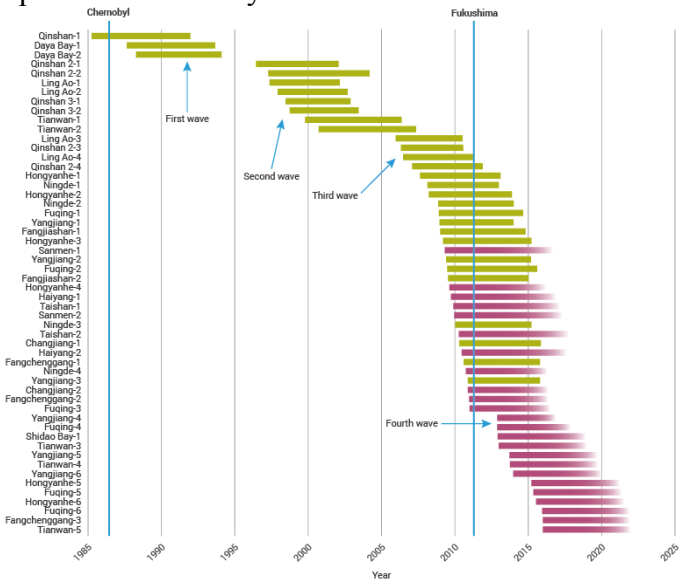


Figure 1. Nuclear reactors in operation in China

Many problems facing the development of nuclear power have been known for decades and recently some new problems have appeared. In the first family are the questions of waste management, of ore reserves, of nuclear safety, of public information and of the necessity of high level training and R&D. In the second family are matters of reactor lifetime and dismantlement costs. In parallel, assets of nuclear power have recently been brought in the limelight: the absence of carbon emissions, important progress in nuclear safety and the limitations of solar and wind energies.

The dominating idea is that Generation III reactors have reached a very high level of safety and efficiency and that Generation IV reactors will make many of the earlier traditional concerns obsolete, a closed nuclear fuel cycle providing a solution to the problems of waste storage and ore reserves at the same time as offering a high level of safety. Accordingly, the report ignores questions of ore reserves, although they only cover a century or so for the present Generation II and III uranium burning reactors. Indeed, China claims to hold over two million tonnes of uranium deposits, placing it in a privileged

[23] http://www.world-nuclear.org/information-library/country-profiles/countries-a-f/china-nuclear-power.aspx

position in this domain. Similarly, the report disposes of the waste storage problem by simply stating that solutions already exist for the storage of short and medium lifetime wastes and that high level long life wastes (HL-LLW) can easily be stored in deep geological layers. Objectively, it is not incorrect, but I can imagine that such statements will be criticized by Green organizations. It is only in the Generation IV perspective that they become uncontroversial.

On the question of nuclear safety the report is poorly organised, the issue being treated in at least three different sections when it would have been easy to address it directly and clearly in a single place and to provide objective irrefutable data. Instead we can read in one place that the probability of incidents implying core fusion has been reduced by a factor 10 in both France and China for the existing fleet of operating Generation II reactors as well as for Generation III reactors; we can read in another place that the average annual dose received by workers of the nuclear cycle is of the order of one milliSievert, significantly smaller than the dose received from natural radioactivity; in a third place, we learn that, per GWe of produced electricity, the coal cycle generates significantly more ionizing radiations than the nuclear cycle; in a fourth place, we find the statement that no important damage, including deaths, due to the direct effect of radiation has been detected following the Fukushima incident and that the impact on public health is minimal, the main impact being on mental health due to the stress produced by the massive evacuation; this contrasts with the confusion in the public between the consequences of the tsunami (over 22'000 deaths) and those of the nuclear incident. A very important recommendation of the report, which will surely be welcomed by the Chinese decision makers, is to favour an approach of safety issues based on risk appreciation, as already adopted by major nuclear nations, safety requirements being dealt with in balance with associated benefits. An approach requiring instead the best currently available technology to be systematically adopted is clearly rejected.

On the questions of public information and of the necessity of high level training and R&D, the report is essentially repeating the wishful thinking statements and pious hopes that we have been hearing for half a century. While it has been frustrating to witness their blatant inefficiency, I imagine that the authors of the report trust that the need for nuclear power will soon become so obvious that a vigourous surge will appear vital. Finally, on the question of reactor lifetime and dismantlement costs, the report is simply silent, which one might consider irresponsible. Of course, the issue is less acute in China, where most reactors are young, than in France and other developed countries, where an important fraction of the reactor fleet is approaching age limit. Curiously, the report insists at length on the need not to miss Industry-4 developments, probably the effect of a fashion trend.

Among the main arguments in favour of nuclear power, the lack of carbon emissions is naturally underlined: it is indeed a strong asset and current emphasis on environmental concerns places it in the limelight. Of utmost importance is the recognition of the inability of renewables such as solar, wind and biofuels to cover more than a quarter or so of the energy needs of the planet. The demonstration has been made by Germany, which has installed renewable energy sufficient to cover the totality of its needs but which, in practice, covers only some 15%. It is now generally accepted that it would be irresponsible to claim that progress in electricity storage would change the situation over any reasonable amount of time. As a result, each country has to organise its energy resources as a "mix", making the best possible use of each form of energy and not disregarding any, in particular not the nuclear.

Reactors of Generations III and IV

Rather than pursuing a more detailed analysis of the China-France report, I find it more interesting to comment on the window that it opens on the future, in particular in China and in the region. What Chinese decision makers will retain from it is the incentive to go ahead bravely with an audacious development of nuclear power along the lines of Generation III and IV reactors. The influence of Green organisations is much less in China and Russia than it is in the western world and I imagine that the recommendation for an objective evaluation of risks, using a similar approach for all energy sources and rejecting irrational antinuclear considerations, will be easily accepted in spite of the growing awareness of the population.

The dangers caused by the coal cycle, with large scale air pollution and recurrent fatal incidents in the mines, are a major public concern and the promise of a safer energy source will be more easily accepted in China than it is in Europe. The unavoidable increase of the energy needs, particularly electric energy, in this rapidly developing region of the world, together with the strong limitations attached to renewables and the nuisances and drawbacks attached to fossil fuels, will make nuclear energy a major element of the mix that will ultimately be converged to.

Most reactors in current operation are Generation II reactors; they burn uranium, usually in the form of the more stable uranium dioxide. As natural uranium is 99.3% ^{238}U, which cannot be fissioned by thermal neutrons, and only 0.7% ^{235}U, which can, the ore needs to be enriched to ~3 to 5% ^{235}U before being used in reactors. Dioxide powder is compacted to cylindrical pellets and heated to produce ceramic nuclear fuel stacked and filled into metallic tubes (fuel rods) usually made of zirconium alloy (which caused hydrogen production and explosion at Fukushima). A typical reactor core contains some 40'000 rods, each ~1 cm in diameter and ~4 m in length. Reactors generally use water as a coolant, either pressurized (PWR, pressurized water reactors) to allow reaching temperatures higher than 100^{o}C or boiling (BWR, boiling water reactors). The main difference between BWR and PWR is that in a BWR the reactor core heats water, which turns to steam and drives a steam turbine. In a PWR, the reactor core heats water that does not boil but exchanges heat with a lower pressure water system, which turns to steam and drives the turbine.

Construction of Generation III reactors began in the early 1990s and will dominate the market in the coming decades. Their designs developed from Generation II designs with improved safety and more stringent safety objectives and requirements, including a significant reduction of the probability for core melt incidents and providing confinement of the molten core. Economic aspects are only second to safety and include improved fuel technology, superior thermal efficiency and standardization for reduced maintenance and capital costs. Compared with Generation II reactors, Generation III/III+ reactors (the distinction between III and III+ is only quantitative and unimportant in the present context) reach over an order of magnitude lower core damage frequency, use 17% less uranium for a same generated electric power and have a 50% larger lifetime. A list of Generation III/III+ reactors in current operation or construction is given in Table 1. Remarkably, with the exception of the EPRs (European Pressurised Reactors) under construction at Flamanville and Olkiluoto, they are all located in Asia, with China dominating the lot. Like the European EPR projects, several others in Europe and the United States have met difficulties and oppositions such that their future is at least unclear, often severely compromised; they are not listed in the table.

Contrary to Generation III/III+ reactors, which developed in the continuity of Generation II designs, Generation IV reactors are conceptually different, mostly by using fast rather than thermal neutrons to induce fission, thereby opening the door to a closed fuel cycle making nuclear energy "renewable", a considerable asset on the long range in a context of sustainable development.

Fast Neutron Reactor (FNR) designs have existed for decades. They aim at generating fissile material, possibly more than is consumed, in which case one speaks of Fast Breeder Reactors (FBR). Such a FBR is in current operation in Russia (Beloyarsk-4, 0.8 GWe), which satisfies the conditions to be considered Generation III. Another (0.5 GWe) will be commissioned in India, at Kalpakkam, by the end of the year. The idea is that a chain reaction maintained by fast neutrons (~10^4 times faster than thermal neutrons) can generate more fissile material than it consumes: one surrounds the fissile ^{235}U core (fissile means that thermal neutrons, with velocities of the order of 2 km/s, are sufficient to induce fission) with a blanket of natural (non-fissile) uranium (^{238}U) which produces the primary fissile isotope of plutonium, ^{239}Pu, by capture of a fast neutron that escaped from the core. The reactor core is designed to obtain a high breeding ratio, preventing deceleration of the fast neutrons by using proper coolants: water is excluded and sodium is particularly well suited. The ^{239}Pu produced in the natural uranium breeder blanket can then be recycled into fuel, allowing for uranium to be utilized up to 60 times better than in thermal reactors.

Table 1. Generation III/III+ reactors.

Type	*Country*	*Name/place*	*GWe*	*Start const.*	*End const.*	*Start oper.*	*Planned*
BWR	*Japan*	*Kashiwazaki-6*	*1.4*			*1997*	
PWR	*S-Korea*	*Kori*	*1.4*			*2016*	
PWR	*China*	*Yangjiang-5*	*1.1*			*2018*	
PWR	*China*	*Fangchenggang-3*	*1.1*	*2018*			
PWR	*China*	*Fangchenggang-4*	*1.1*	*2018*			
PWR	*China*	*Fangchenggang-5*	*1.1*				*x*
PWR	*China*	*Fangchenggang-6*	*1.1*				*x*
PWR	*China*	*Tianwan-1*	*1.0*		*2018*		
PWR	*China*	*Tianwan-2*	*1.0*		*2018*		
PWR	*China*	*Tianwan-3*	*1.0*		*2018*		
PWR	*China*	*Tianwan-4*	*1.0*		*2018*		
PWR	*India*	*Kundakulam-1*	*1.0*			*2014*	
PWR	*India*	*Kundakulam-2*	*1.0*			*2016*	
PWR	*India*	*Kundakulam-3*	*1.0*	*2017*			
PWR	*India*	*Kundakulam-4*	*1.0*	*2018*			
PWR	*India*	*Kundakulam-5 to 8*	*1.0*				*x*
FBR	*Russia*	*Beloyarsk-4*	*0.8*			*2016*	
PWR+	*China*	*Sanmen*	*1.2*		*2017*		
PWR+	*China*	*Shidaowan-1*	*1.4*	*2016*			
PWR+	*China*	*Shidaowan-2*	*1.4*	*2016*			
PWR+	*China*	*Taishan*	*1.7*		*2017*		
PWR+	*Turkey*	*Sinop*	*1.1*		*2023*		
PWR+	*Russia*	*Novovoronezh II*	*1.1*			*2017*	
PWR+	*Russia*	*Leningrad*	*1.1*			*2018*	
PWR+	*Turkey*	*Akkuyu*	*1.1*		*2022*		
PWR+	*France*	*Flamanville-3*	*1.6*	*2007*		*>2018*	
PWR+	*Finland*	*Olkiluoto-3*	*1.6*	*2005*		*>2018*	
PWR+	*China*	*Taishan-1*	*1.7*	*2009*		*2017*	
PWR+	*China*	*Taishan-2*	*1.7*	*2010*		*2018*	

Generation IV nuclear reactors is a concept defined by an international forum including Japan and South Korea from Asia but excluding Russia, India and China. It covers reactor designs selected on the basis of being clean, safe and cost-effective means of meeting increased energy demands on a sustainable basis, while being resistant to diversion of materials for weapons proliferation and secure from terrorist attacks. Most employ a closed fuel cycle to maximise the resource base and minimise high-level wastes to be sent to a repository. Temperatures range from 510°C to 850°C, opening the door to thermochemical hydrogen production, and powers range from 0.15 to 1.5 GWe. Most have significant operating experience already in most respects of their design, which suggests that they can be in commercial operation before 2030. However, to address non-proliferation concerns, they are not conventional fast breeders: ^{239}Pu is no longer produced in a breeder blanket but within the core, where burn-up is high and

the proportion of plutonium isotopes other than ^{239}Pu remains large. Moreover, reprocessing the fuel will enable recycling without separating plutonium.

Recently, increased attention has been given to the development of small nuclear reactors[24], which may be of particular interest to Viet Nam in view of its elongated geography. There is no place in the present article to develop this issue further, but it deserves very serious consideration as it allows for significant reductions of the capital costs and for providing power away from large grid systems.

It is not the place here to enter into the details of various possible generation-IV reactor designs, the reader curious of learning about them can easily access exhaustive information on the web. I prefer to briefly review the involvement of China in current developments: its progress is impressive and its relevance to Vietnamese energy policy is obvious.

Nuclear Power in China

An up-to-date comprehensive review of China's nuclear power has been produced by the World Nuclear Association (footnote 3), which the interested reader is invited to consult. Not so long ago, one might have expressed doubts on the ability of China to construct and exploit successfully nuclear power plants: it was lacking competence and the necessary safety culture. Moreover, an anti-corruption campaign initiated in 2012 has shown that corruption was widespread among both high-ranking officials and lower-level civil servants and several prominent cases have plagued China's nuclear sector. Today, the country is going ahead successfully and responsibly on all fronts of its nuclear power development policy and many countries around the world can envy its performance.

In its 13th Five-Year Plan[25] (2016-2020), six to eight new nuclear reactors are to be approved each year for construction. Non-fossil primary energy provision, which was 10% in 2013, should reach 15% by 2020 and 20% by 2030. In June 2015, China took the commitment that its 2030 carbon emissions would not exceed twice the 2005 value, as a contribution to the UN effort on climate change mitigation and adaptation. Between 2005 and 2020 the annual average new nuclear capacity will be 3.4 GWe/yr and increase to 9.0 GWe/yr between 2020 and 2030. By around 2040, PWRs are expected to level off at 200 GWe and fast reactors progressively increase from 2020 to at least 200 GWe by 2050 and 1400 GWe by 2100.

China has shown unprecedented eagerness to achieve the world's best standards in nuclear safety, systematically requesting and hosting Operational Safety Review Team missions from IAEA and providing for one yearly external safety review for each plant. In December 2013, together with Japan and South Korea, it agreed to cooperate on nuclear safety and quickly exchange information in nuclear emergencies. Following the Fukushima accident the government suspended its approval process pending a review of lessons which might be learned from it. Safety checks of operating plants were undertaken immediately, and a review of those under construction was completed in October 2011. Resumption of approvals for further new plants was suspended until a new nuclear safety plan was approved.

Technology has been drawn from foreign countries, the latest from the PWR AP1000 produced by Westinghouse/Toshiba, one of which will start operation in Samnen in the first quarter of 2018. The Chinese version, CAP 1000, and its successor, CAP 1400, will be the main basis of technology development in the immediate future. This has led to a determined policy of exporting nuclear technology with Chinese intellectual property rights and backed by full fuel cycle capability. This policy is being

[24] http://www.world-nuclear.org/information-library/nuclear-fuel-cycle/nuclear-power-reactors/small-nuclear-power-reactors.aspx

[25] The main points of the plan are: Complete four AP1000 units at Sanmen and Haiyang; build demonstration Hualong One reactors at Fuqing and Fangchenggang; Start building the demonstration CAP1400 reactor at Rongcheng; Accelerate building Tianwan units 5&6; Start building a new coastal power plant; active preparatory work for inland nuclear power plants; reach 58 GWe nuclear operational by end 2020, plus 30 GWe under construction by then; accelerate and push for building demonstration and large commercial reprocessing plants; strengthen the fuel security system.

pursued at a high level politically, as one of 16 key national science & technology projects, making use of China's economic and diplomatic influence.

In summary, the determination of China to aim for world leadership in nuclear technology and to make nuclear energy the foundation of its power-generation system in the next 10 to 20 years, adding as much as 300 GWe of nuclear capacity over that period must be taken seriously. China has now demonstrated its ability to master the technology as well as the safety, economic and political aspects.

What about Viet Nam?

Nuclear power technology requires a sustainable, responsible and rigorous management. It implies determination and continuity in the decisions being taken, a strong commitment to these in their implementation and a clear vision of the long term. The lack of continuity in nuclear power policy, resulting largely from the pressure of Green organizations, has been the main cause of the decline of nuclear energy in Europe. On the contrary, China has shown in the past two decades or so that it was able to change style in a short period and adapt to the constraining demands of a rigorous discipline. Apart from the event of major instabilities or conflicts in the region, in which case the present considerations would anyhow become futile, the next decades will witness a growing contribution of nuclear energy in the mix adopted by China, which will obviously influence the energy policy of the whole region.

There are of course many lessons to be learned from the China experience for developing countries that aim at including nuclear power in their energy mix. The recent failure of Viet Nam to sustain its effort in this direction should not result in renouncement. We should not waste the investment that has been placed on nuclear technologies in the past two decades or so. In particular, Viet Nam must follow up on the training that was offered to several young engineers who studied in Russia and other countries in preparation for the construction and exploitation of the Ninh Thuan power plant. We must continue training programmes such as NEST (Nuclear Energy Specialists Training), and do our utmost to improve their efficiency. We must develop our effort to contribute actively to Research and Development projects in the domains of nuclear technology, including Generation IV reactor designs, and of all issues related to nuclear safety.

Independently from the use of nuclear technologies in electricity production, their contribution to medicine and industry will keep growing over the years to come and the country must develop skills and talents that have the ability to master them. The use of nuclear power in making weapons remains a threat for the entire world, as recently evidenced by the North-Korean missile tests and the reaction of the president of the United States, and all countries must make sure that they understand the technology that is implied. Even if one considers that the construction of nuclear power plants in Viet Nam is postponed to a distant future[26], one must keep training engineers and scientists who follow the progress in the world, in particular in neighbour China, and offer them the opportunity of spending time in foreign nuclear plants for training. The training offered by Vietnamese universities in the domain of nuclear sciences and technologies must be revised in depth in order to adapt to modern times and to the current environment. The existence in Da Lat of expertise in nuclear reactor operation should not be underestimated. The establishment of a national nuclear training centre is mandatory, as it has been, in my opinion, for the past two decades or so but has been largely ignored. I understand that progress has been recently made in this direction in the framework of a Centre for Nuclear Energy Science and Technology (CNEST); it needs to be vigorously pursued.

All this requires a change of style. If we were to fail in training engineers and scientists having nuclear expertise, we would be condemned to a state of ignorance and incompetence that will irremediably hinder the progress of the country.

[26] However, the electricity needs of the country will keep increasing at a yearly rate exceeding 10% unless the current economic development of the country is forced to drastically slow down. Provision of the energy required to sustain such a development is a very difficult challenge that the country cannot escape facing in a not too distant future.

ANOTHER NOBEL PRIZE REWARDING ASTROPHYSICS

This year's Nobel Prize in Physics was awarded to Rainer Weiss, Barry C. Barish and Kip S. Thorne *"for decisive contributions to the LIGO detector and the observation of gravitational waves"*.

Over a year ago, on the occasion of the first detection by LIGO of gravitational waves emitted by a pair of merging black holes, I took the opportunity to comment in these columns on the role of gravity in modern physics. I shall not repeat it here but simply add a few comments that may shed some light on the event.

The search for gravitational waves started half a century ago. Their existence was not really questioned but their detection was a challenge that has motivated many physicists to invest major effort in their search.

How gravity is transported in space had been a question in the mind of physicists for ages; three centuries ago, when Newton was asked about what he had to say on this, he eluded the question by claiming that he did not forge unfounded hypotheses, "*hypotheses non fingo*". At the end of the nineteenth century, after Hertz's discovery of electromagnetic waves in 1887, several physicists speculated about the existence of gravitational waves, such as Heaviside in 1893, Lorentz in 1900, and Poincaré in 1905. But it was only a century ago (precisely) that Einstein introduced the concept in the framework of General Relativity; however, in the first half of the twentieth century, doubts were expressed on the "reality" of gravitational waves: do they carry energy or are they simple mathematical artefacts? It was not until 1957 that the issue was definitively settled, in particular by Feynman; by then, progress in our understanding of modern physics had dissipated early doubts.

Their existence being no longer doubted, the issue of their detection came on the agenda. Joseph Weber was first to face it seriously. A Navy officer during World War II, he was an excellent electronics engineer and instrumentalist and had made essential contributions to the development of the laser. His first detectors, aluminium cylinders 2 m long and 1 m in diameter, detected what he thought were gravitational waves at the rate of one a day, enough, if it had been true, for the Universe to convert all its energy into gravitons in some 50 million years, as Dick Garwin then remarked! Weber died in 2000; while his claims of having detected gravitational waves have been proven wrong by a host of other experiments, his legacy has been to start a line of research that many doomed hopeless. I remember attending advisory scientific committees in the eighties, when what was going to become today's detectors, LIGO and VIRGO, were asking for funding: the particle physicists and astrophysicists communities were each claiming that it was none of their business and were offloading the burden onto each other.

In the wake of first Weber's detectors, antennae of continuously increased sophistication and sensitivity have been built and operated around the world. I remember, at CERN, in 1972, when I was PS coordinator, having been involved in such an operation. The PS coordinator (PS stands for proton synchrotron, the job was given to experimental physicists for a year duration) was meant to serve as go-between between the people in charge of the operation of the accelerator and its users. At that time, Edoardo Amaldi and his Italian colleagues had brought an antenna to CERN where liquid helium was available for the cryogeny; as they had no one at CERN to keep an eye on it, my responsibility was simply to make sure that the helium Dewar was not empty. Retrospectively, one may be amazed by the candour of the pioneers, the sensitivity of the first antennas being so far away from what is required and took fifty years to become within reach! A review of the technical progress that has been accomplished is beyond the scope of this article[27]; it should be enough to recall that we are talking about detecting movements that are at nuclear, not atomic scale: the LIGO events detect movements smaller than a per cent of a proton diameter!

If the detection of gravitational waves did not come as a surprise, it rewards fifty years of ingenious and persistent effort and does mean a major success of modern experimental physics. It is a chapter of

[27] See for example the review by Aguiar, https://arxiv.org/ftp/arxiv/ papers /1009/1009.1138.pdf

contemporary physics that the community of scientists can be rightly proud of and its history offers many examples of excellence. The rules of the Nobel Committee are such that no more than three laureates are eligible each year. This is always a difficult choice, sometime impossible as has been the case, for example, for the discoveries of the top quark and of the Higgs boson. In the case of the gravitational waves, more than 1'200 scientists from around the world participate in the LIGO Scientific Collaboration. Yet, this year's choice rewards high-fliers whom we can be proud of and who set an example for the young generation, which is precisely what the Nobel Prize is good for. We shall hang with pride their pictures on the wall of our office, in the Department of Astrophysics of the Viet Nam Space Centre, at VAST, next to their nineteen predecessors. Rainer Weiss has been involved in gravitational wave research from the very beginning, and has been the promoter of the interferometer technique, which proved to be so successful. He also contributed to the early days of cosmic background research with COBE. Kip Thorne is a theorist, kind of the guru of the discipline; a student of John Archibald Wheeler, he became interested in general relativity very early and kept close contact with experimenters, playing an essential role in demystifying for them the intricacies of the theory and in advising them for the design and exploitation of the LIGO detector. Barry Barish spent much of his career as a particle physicist, making major contributions to neutrino experiments searching for neutral currents and to underground experiments searching for exotic particles and events; he joined LIGO at the beginning, in the mid-nineties, where he made best use of his experience by providing excellent leadership.

The field will now develop and progress, with increased sensitivities and new detectors, not only VIRGO and LIGO, but also KAGRA in Japan and, in a few years, LISA in space. A spectacular illustration was offered to us a few days ago, when we learned that a neutron star merger that had been observed jointly by LIGO and VIRGO had also been detected in space by HUBBLE (optical), INTEGRAL (gamma rays) and others[28]. No doubt, it opens a new window on astrophysics and will tell us about black holes and neutron stars in the Universe. Whether it will be able to reach as early as the Big Bang is far from obvious, as it is not clear how much light it will shed on our understanding of gravity. The main evidence for the validity of General Relativity today is the Hulse and Taylor detection of the decline of a pulsar binary orbit caused by the emission of gravitational waves but the precision with which the theory is verified is poor in comparison with what we are used to in special relativity and atomic physics. Indeed, we know that the couple Quantum Theory-General Relativity does not hold water when we approach the Planck scale, probably the main mystery of contemporary physics. For half a century, our approach to the problem has been Superstring Theory, including additional curled space dimensions. While it has made spectacular progress, leading today to the concept of M-theory, it is still considered by many as unsatisfactory. In particular, the inconsistency between gravity and quantum physics remains poorly understood, which, recently, has been leading a few theorists to reconsider the issue with a new eye, in particular by investigating what the behaviour of a quantum scale black hole should be and developing drastically new ideas such as "emergent gravity". But this takes us too far away from focus and must be kept for a future article.

When will Viet Nam wake up to the reality of modern physics? Isn't it sad to see astrophysics, probably the most dynamic field of physics today, largely ignored by Vietnamese universities? Recently, a young Vietnamese astrophysicist proposed to include astrophysics in the syllabus of at least one of the Vietnamese doctoral schools; his proposal was turned down. Today, our students, who work with us for a master or PhD, have to hide it under fake names such as "atomic physics" or "nuclear physics" as if astrophysics were a swear word that should not be pronounced. The argument to turn the proposal down was that there are not enough astrophysicists in the country! In 1944, when Vo Nguyen Giap was appointed head of the yet to be formed Viet Nam Liberation Army, he had no military experience and the army did not exist. We live in a country where courage, determination and boldness have written the most

[28] http://sci.esa.int/hubble/59672-hubble-observes-source-of-gravitational-waves-for-the-first-time-heic1717/
http://sci.esa.int/integral/59664-integral-sees-blast-travelling-with-gravitational-waves/
https://www.darkenergysurvey.org/des-gravitational-waves-papers/

glorious pages of its history. Why do conservatism and immobilism prevail today? Why do we behave as if we wanted to prevent progress?

PARTICLES, GRAVITY AND THE UNIVERSE: A RECENT CONFERENCE IN HANOI[29]

Early December, Hanoi hosted a conference on the frontiers of modern physics covering particle physics, astrophysics and cosmology[30], called PGU2018, which I had the pleasure to attend. Here is not the place for a detailed report on the topics that were addressed and their recent achievements; I should like instead to introduce them briefly and to comment about the thoughts that such a meeting may inspire to whoever cares about the progress of Vietnamese science.

Particle physics

While nearly absent from the curriculum of Vietnamese universities, particle physics, astrophysics and cosmology share a privileged position at the frontier of modern physics. In the second half of the past century, in less than three decades, particle physics has put together an incredibly successful picture of the world as seen at short distances, the so-called Standard Model (SM) of particle physics. Its beauty rests on the simplicity of the premises on which it is erected: a few matter particles, called fermions, related by simple symmetry properties that reduce them to essentially two different particles, a so-called "lepton", of which the electron is the most emblematic realisation, and a so-called "quark", of which protons and neutrons are made. Each of these exists in different forms related by symmetries, as the two faces of a same coin. Some of these symmetries are well understood, as that relating particles to anti-particles and those associated with the strong, weak and electromagnetic interactions, but one remains mysterious: each of these particles exists in three apparently identical copies, apart for their different masses; one speaks of "flavour symmetry". When the first evidence for such replication was obtained with the discovery of the muon, a copy of the electron, Isidor Rabbi famously wondered: "Who ordered that?"

A second ingredient of the SM are the so-called "gauge bosons" that mediate the interactions known to act between particles: the strong interaction, which keeps together protons and neutrons inside atomic nuclei, is mediated by the "gluon"; the weak interaction, the archetype of which is beta decay, is mediated by the "weak boson"; and the electro-magnetic interaction is mediated by the familiar photon. Remarkably, the gauge bosons do not need to be artificially introduced in the theory but their existence is a direct consequence of the fermion symmetries and of a simple law of invariance inherent to quantum physics, called "gauge invariance".

The fermions and gauge bosons have all been discovered but the weak boson, contrary to the gluon and photon which are massless, is very massive; this complicates the theory and requires the presence of yet another boson, the so-called "Higgs boson", which was discovered at CERN over five years ago. For now four decades, experiments have been confirming with increased precision the SM picture, providing no hint at solving the puzzles that particle physics is still keeping for us: in addition to the mysterious flavour symmetry, several clues suggest that the SM is but a low energy realisation of a more general and unified theory that governs energies some fifteen orders of magnitude larger than currently explored by experiments. This disproportion with respect to the scale of the SM world generates problems (grand-unification and hierarchy) as may also do, toward low energies, the so-called neutrinos, which have a mass six orders of magnitude smaller than the otherwise lightest known fermion, the electron. The fear that the answer to the puzzles that the SM leaves us with might be out of reach of experiments led some to speak of a crisis of particle physics but the general opinion is obviously more optimistic, hoping for soon-

[29] Published in Tia Sang

[30] The Second International Workshop "Particles, gravitation and the Universe", Hanoi, 10-14 December 2018. https://iop.vast.ac.vn/theor/conferences/pgu2018/

to-come discoveries of deviations from the SM predictions, opening a window on what is currently called "physics beyond the SM".

Cosmology

When looking at large distances, the landscape is dominated by gravity, which is neglected in the SM picture. Conversely the quantum physics inherent to the SM can be essentially ignored when dealing with gravity on large scales. A major property of gravity is that it applies the same way to all particles, suggesting that it should be described as a deformation of space-time rather than an interaction in the sense used for the SM, which together with special relativity is at the basis of general relativity. No deviation from the predictions of general relativity has been explicitly unravelled and the recent detection of gravitational waves, the existence of which is a necessity in any sensible theory of gravitation, opens the way to more precise tests than currently available. Yet, two major flaws indicate that our understanding of gravity is incorrect: one is the complete failure of our model of the Universe to match observations, the other is the incompatibility of general relativity and quantum physics at what is called the "Planck scale" where both are expected to play an important rôle.

The picture we have of the Universe implies that it was born some 14 billion years ago in what is called the "Big Bang" and has been since expanding and cooling. The formation of nuclei, mostly helium, 3 minutes after the Big Bang and of atoms, 400'000 years after the Big Bang, provide the main sources of information on which we construct the current picture that we have of the evolution of the Universe. Unfortunately observations of stars, galaxies and the gas and dust that populate the space in between account for only 5% of what this picture predicts; of the remaining 95%, one has good reasons to believe that a quarter of it is made of a form of matter that has essentially no other interaction than gravity; it is called "dark matter" and all attempts at revealing its existence have failed until now; of the other three quarters, we have no idea of what they consist of, all we can do is to give it a name: "dark energy". In addition to these two major puzzles, our current picture of the Universe is facing a third problem: that of understanding the very first moments of its life, when it is believed to have expanded exponentially for a very short time, what is called "inflation".

The Planck scale

But another problem that both general relativity and quantum theory are facing is probably, and by far, the most important; many believe that solving it would answer most of the other questions that I have described above; general relativity and quantum theory are incompatible at a scale called the "Planck scale", corresponding to $\sim 10^{19}$ proton masses, or 10 micrograms, and 10^{-33} centimetres. At such a scale, the energy density of gravity becomes so important that it must violate the basic laws of quantum physics, the so-called Heisenberg uncertainty relations. The Planck scale coincides with the scale of the Universe just after the Big Bang, at the time of inflation, and with the scale at which interactions between particles are expected to unify, only two orders of magnitude below.

New physics is required to describe the Planck scale. For over three decades, research has followed the road of "Superstrings" where "super" stands for supersymmetry, a symmetry relating fermions to bosons and where "strings" and "branes", with sizes at the Planck scale, are the basic 1-d and 2-d objects of the theory, which must be hosted in a space-time of 9+1 dimensions, of which 6 are compactified. Some two decades ago, one realized that a more general theory, in 10+1 dimensions, called M-theory, unifies 11-d supergravity with the five consistent versions of string theory as limiting cases, different versions of string theories being related by highly non trivial duality relations. The extreme mathematical complexity of standard superstring theory and the experimental inaccessibility of the Planck scale, together with the lack of encouraging signals, is causing a surge of different approaches based on the direct study of quantum size black holes without biasing influence of string prejudices.

The Conference

The conference covered nicely all above topics and provided a good picture of the involvement of Asian physicists, and in particular Vietnamese physicists, in their progress. It was attended by some hundred participants, of whom one half was from Vietnam and one third from other Asian countries, with a particularly strong Japanese participation. Prestigious invited speakers summarized the state of the art. Five of them reported on the achievements, progress and perspectives of major experimental installations, including the LHC collider that measured the mass of the Higgs boson to a precision of 2 permil and detected some of its very rare decay modes and three installations based in Japan: the long baseline neutrino experiment T2K, showing signs of CP violation and including the refurbishing of the Superkamiokande detector; the Belle II b-quark factory now starting operation with an upgraded detector; and soon to start collecting data the new underground cryogenic gravitational wave detector KAGRA. On a longer time scale the high luminosity LHC programme and the hyper-K Japanese project set the bases for a productive future while the Litebird satellite, with a very strong Japanese participation, is being considered as a serious candidate for the search for primordial gravitational waves emitted at the time of inflation.

Nine invited theory talks reported about progress in the fields of general relativity and Planck scale physics with particular emphasis on the roles of gravitational waves and of black holes, the detection of gravitational waves having opened a new window on cosmology and on the study of the population of the Universe in neutron stars and black holes.

The status of astrophysics research in Vietnam was reviewed with emphasis on the work of the team of the Department of Astrophysics of the Vietnam Space Centre, shared between stellar physics (protostars in formation and stars at the end of their lifetime) and the study of galaxies of the early Universe at large redshifts.

Six out of 21 contributed talks were presented by Vietnamese physicists and illustrated the diversity of the research work being accomplished in the country.

Before departing, the participants expressed their warm gratitude to Nguyen Anh Ky and his team, from the Institute of Physics, for his dedication to having made the conference a success.

Lessons for Viet Nam

In his summary talk, Tom Browder commented on the opportunities that the field offers for Viet Nam to make major contribution to its progress, taking advantage of the investment made by the international scientific community to successfully face the many challenges that it presents. He noted the heavy brain drain that the country is enduring and recognized that previous attempts to stop it have failed. To reverse the situation, he said that all it takes is a long term vision and high level support to the constitution of skilled research teams.

Indeed, the Vietnamese research effort is scattered and sprinkled over too many isolated individuals. Many were trained abroad and, when back home, simply continued collaborating with their foreign hosts without being given a chance to build a Vietnamese team around them. They do train students but cannot keep any to work with them on a long term. Too often, the author list of the publications in which they take part includes no other Vietnamese name than their own. When they retire, they leave no legacy behind them and their contribution to the progress of Vietnamese science is confined to the time during which they were active.

Such individualistic approach to science, deeply rooted in the Vietnamese culture, is preventing progress. We need to recognize that the talents of a team are much more than the sum of the talents of the individuals who make it. By exchanging and confronting ideas, by sharing knowledge and skills, a team generates the atmosphere of excellence that research needs to be successful.

Too often, we seem to have the idea that being a good scientist is imprinted in our genes. It is not, of course, and there are as many young Vietnamese having the skill and aptitude to become a good scientist as there are in any other country. Hard work, intellectual and moral rigour, determination and courage, in a word all the qualities that make scientific excellence carry no passport. Curiously, we feel proud when a Vietnamese scientist who left the country long ago is honoured by international recognition. We should

instead feel sorry not to have been able to recognize his talent at an early stage, sorry not to have been able to give him proper training, motivation and encouragement at home, sorry not to have been able to give him the support that foreign scientists gave. We may feel happy to see his talent receive international recognition to the extent that, as some do, he feels committed to help his native country to develop and to progress; but proud we should not feel.

While such pride is out of place, its contrary, a complete lack of confidence in the skills and talents of the young generation and in what they are able to achieve is deeply harming us and severely preventing progress. The wealth of the country is in the brains of the young generation, we should not waste it by failing to recognize its value.

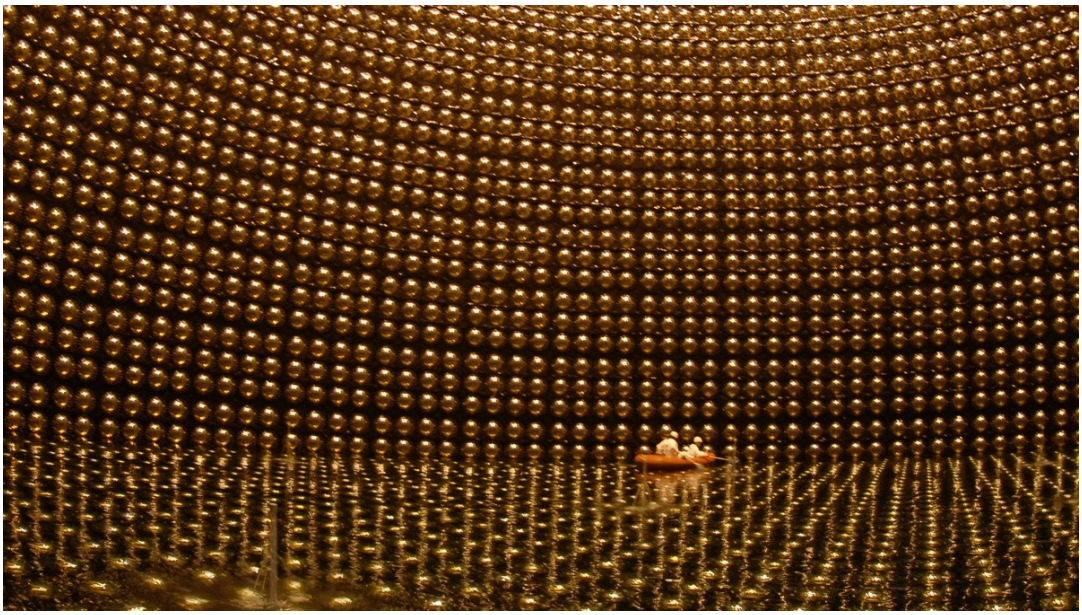
It is time to encourage team work in the country and give proper support to scientists who have the skill and talent to build a team around them. This applies to theorists as well as to experimenters and to all fields of science. It is already somewhat recognized in condensed matter physics and material sciences, where several successful Vietnamese research teams exist, but is not properly accepted in the fields covered by the PGU2018 conference.

I know of efforts to encourage the promotion of astrophysics in the curriculum of Vietnamese universities; they have been discouraged and turned down. I know of efforts to simplify the rules governing the award of PhD degrees in case of collaboration with prestigious foreign universities; they have been discouraged and turned down. I know of efforts to avoid wasting money in acquiring expensive instruments that are essentially unused and invest instead in a better funding of the participation of Vietnamese researchers in international conferences, workshops and schools; they have been discouraged and turned down. I know of efforts to build up small teams of excellence in the domains of microelectronics and integrated circuits, from which Viet Nam is nearly absent; they have been discouraged and turned down. I know of efforts to make our learned societies more active, to have them become forums in which young scientists can openly debate and exchange their views on the best way to make science progress; they have been discouraged and turned down; indeed, these societies, such as the Vietnam Physics Society do not even accept foreign members, a remnant of wartime probably.

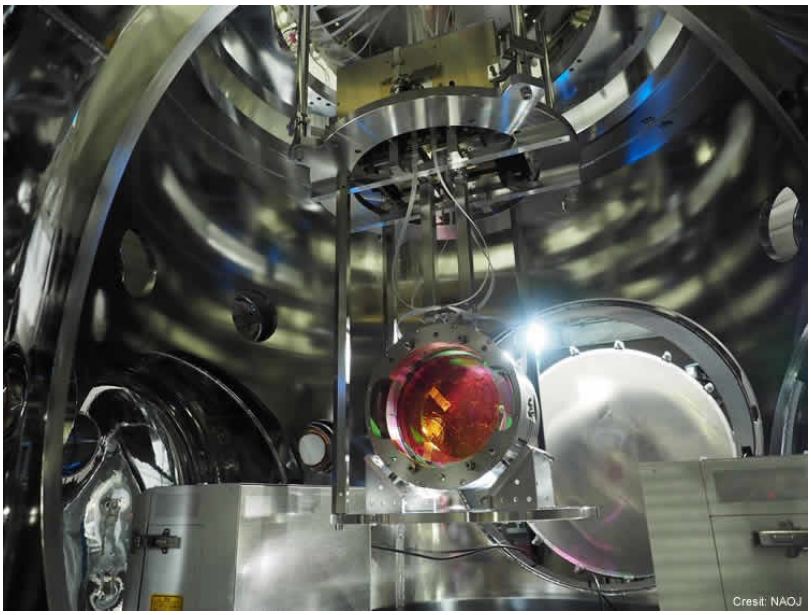
We seem to lack the long term vision that Tom Browder was alluding to in his summary talk. We should ask for support from the international community in the form of international scientific advisory committees that would help us finding the best way to progress. But I know of efforts to do so at the level of institutes as well as national level; they have been discouraged and turned down.

It is time to change style.

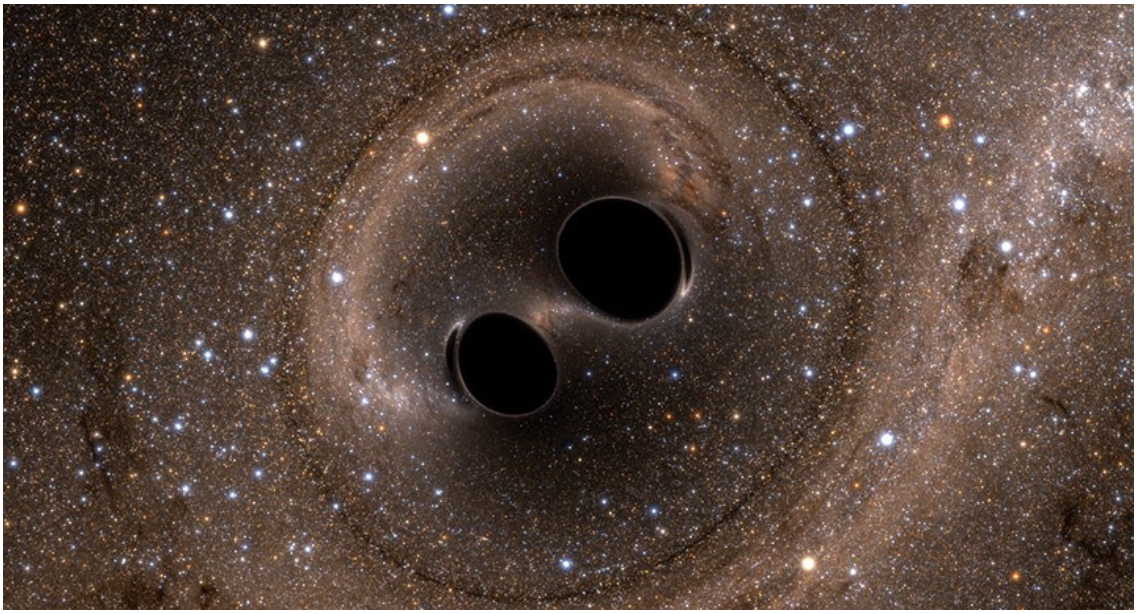
Among the recipients of this year Ta Quang Buu's Prize were two young and brilliant Vietnamese scientists who recently came back to the country. One of them was attending the conference. They are emblematic of what the country needs to make its research progress. To them and to all those who, like them, are the future of Vietnamese science, let us give all the support they need to build or maintain productive teams around them, let us place our confidence in their talent and excellence, let us stop the brain drain that is preventing the country to take the place that it deserves on the international scene. Let us prove Tom Browder right when he predicts that with proper support and a long term vision "the next generation of Vietnamese scientists could be leading the way in many of the areas covered by the PGU2018 conference".



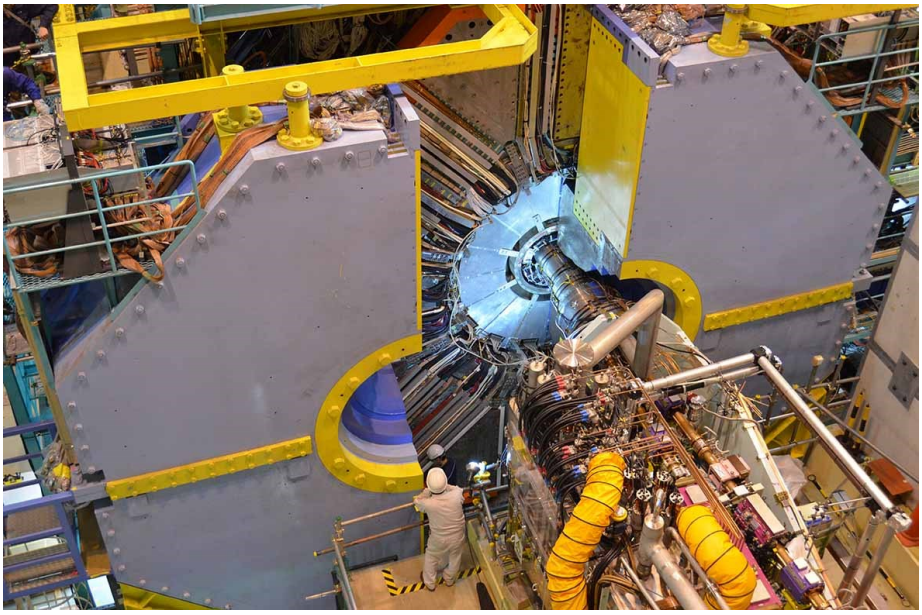
The Japanese T2K long baseline neutrino experiment. The SuperKamiokande detector (here shown when starting to be filled, note the tiny boat that gives the scale) detects neutrinos produced 300 km away in Tsukuba by the accelerator complex of J-Park. It consists of a cylindrical underground cavern some 40 m in both height and diameter filled with 50,000 tons of ultrapure water and covered with 13,000 photomultiplier tubes that detect light from Cherenkov radiation produced by interacting neutrinos. A Vietnamese team is currently being formed to participate in the T2K collaboration and will hopefully be given all necessary support to succeed.



KAGRA is an underground gravitational wave detector that will start operation next year in Japan. It consists of two laser interferometry arms at right angle, each 3 kilometres long, operated at low temperature and under vacuum. Gravitational waves modify the length of the arms by a fraction of nanometres. The picture shows the suspension of the test mass in the vacuum chamber at the end of one of the arms.



Artist view of the merging of two black holes, an important source of gravitational waves detected on Earth.



The Belle 2 detector is seen here being assembled. It is designed to study the decays of so-called *b*-quarks produced in pairs together with their anti-particle counterpart from collisions between electrons and positrons in the high luminosity Super KEKB collider. It started operation early this year and has recently published first results. The Institute of Physics in Ha Noi is a member of the collaboration.

CONTROVERSY OVER THE 2019 BREAKTHROUGH PRIZES[31]

The Breakthrough Prizes are meant to "*honour important, primarily recent, achievements in the categories of Fundamental Physics, Life Sciences and Mathematics*". Among the sponsors of the Prizes,

[31] Published in Tia Sang, August 2019.

we find billionaires close to Internet such as Sergey Brin and Anne Wojcicki, Priscilla Chan and Mark Zuckerberg, Pony Ma and Yuri and Julia Milner. The latter Russian couple gave life to the Foundation that awards the Prizes in 2012. Laureates receive three million dollars; by comparison, a Fields medallist gets 15'000 dollars and a Nobel laureate one million dollars. Anyone may nominate a candidate and committees manned by previous laureates choose the winners in a process that is exposed online and open to the public.

This year's committee for the Fundamental Physics Prizes was chaired by Ed Witten, a superstring guru who was awarded a Fields Medal in 1990. The laureates of the so-called "Special Prize" are Sergio Ferrara, Daniel Freedman and Peter van Nieuwenhuizen for having conceived the idea of Supergravity (SUGRA). This choice has prompted violent criticism from many who argue that one should not reward a "*failed theory*". I disagree with them, and allow me to explain why.

SUGRA was conceived in the wake of SUSY, the theory of supersymmetry, which was born in the early seventies and written in a clear and explicit form in 1974 by Bruno Zumino and Julius Wess. Anyone who has studied SUSY cannot have failed to fall in love with her; it is such a beautiful theory that it seems impossible that Nature missed making use of it; it solves so many puzzles for which we know of no other solution; it unifies in a single object, like the two sides of a same coin, light and matter; the former is known to take the form of three distinct particles, the photon, the gluon and the weak boson while the latter takes the form of two other particles, the quark and the lepton, out of which atoms are made. Having thought of such a counter-intuitive theory is an outstanding tour-de-force that can only inspire admiration and respect. The problem, however, is that the five particles that I mentioned, and that we know to exist, are not paired together and we are forced to assume that, of each coin, we know only one side: the matter particle paired with the photon is neither a lepton nor a quark; we have no other choice than assuming that we do not know what it is; not because it does not exist, but because we have been unable to reveal its existence, probably because it is too massive; all we can do is to give it a name, we call it a photino. When the Large Hadron Collider was built at CERN, we were hoping that it would discover not only the Higgs boson, which it did, but also supersymmetric partners of the known particles, which it failed doing. The frustration that ensued has led many to reject the idea of supersymmetry and to forget about it.

Sadly, the Breakthrough Prize could not be awarded to Bruno Zumino and Julius Wess: both died a few years ago. What this year's laureates of the Breakdown Prize have done is less of a break-through: they rephrased what was known of gravity and general relativity in the SUSY language. For over fifty years the main challenge of fundamental physics has been to understand what happens in the region where gravity and quantum physics are incompatible, what we call the Planck scale. Most efforts have followed the route of so-called superstrings and have led us into a landscape of an extreme mathematical complexity offering very little hope for relating its predictions to realistic experiments. Yet, SUGRA has never failed to follow the progress along this route and has remained all along an important source of inspiration. In its present state, the theory, called M-theory, unifies 11-dimensional SUGRA with the five consistent versions of String Theory as limiting cases, associated in pairs by highly non trivial duality relations.

We cannot simply brush aside with disdain over fifty years of efforts to solve what appears to us as the major puzzle of fundamental physics under the pretext that they have not yet come to fruition; we cannot ignore that over these fifty years, the quest for the unification of gravity and quanta at the Planck scale has generated extremely innovative and inspiring ideas. SUGRA has been an important step in this quest and undoubtedly deserves being recognized and rewarded: the decision of the 2019 Breakthrough prize selection committee is honourable and scientists should refrain from speaking of "*failed theories*". A theory may be criticized for lacking rigour or for ignoring facts, not for "*failing*".

When I look at the past laureates of the Breakthrough Prize, I have no doubt that they clearly count among the most brilliant scientists of the past fifty years; the idea to criticize the successive award committees for their decisions does not come to my mind. A role played by the Breakthrough Prize is to correct some features of the Nobel Prize that one may feel unhappy about: the limitation to three

laureates, which prevents rewarding team work, and the constraint of rewarding theories only after their having been experimentally validated. Examples of the former are with the Higgs boson (2013), dark energy (2015), neutrino oscillations and gravitational waves (2016) and microwave background radiation (2018). Examples of the latter are many and SUGRA is the most recent illustration: there is no doubt that it is a good choice. Of course, some may regret that the Prizes clearly favour theory over experiments and observations; but this orientation was chosen by their founding father, Yuri Milner, who has been himself a theorist for a few years: there is nothing wrong with that.

Yet, I cannot say that I feel comfortable with such excessive sums of money being spent to reward physicists. It seems contrary to basic scientific ethics, offensive to the values that make scientific culture. It seems an insult to Einstein when he says that "*when a man after long years of searching spends time on a thought which discloses something of the beauty of this mysterious universe, he should not be personally celebrated for this. He is already sufficiently paid by his experience of seeking and finding*."

If the Breakthrough Prizes were at the level of, say, hundred thousand dollars rather than three millions, there would be no controversy. One would not talk about the laureates more than one talks about the recipients of the Dirac Medal, the Wigner Medal or the Max Planck Medal, who are of a same level of excellence. The real problem is there, and only there; it is the excessive disproportion of the sums being awarded; this is the true reason for the controversy, not "*failed theories*".

With three million dollars, we could pay decent salaries to the young colleagues with whom I work for nearly a decade; when I say decent, I mean higher by a factor twenty than what they presently earn. Or the Vietnam Physics Society, together with nine other Science societies in the country, could each award generous yearly prizes, of say 1'000 dollars, to the three most brilliant of their young members for as long as hundred years. We cannot refrain from thinking that it would be a much better use of the money.

The same criticism applies to the Nobel Prize. It would seem more reasonable and in better conformity with scientific ethics to set an upper limit of, say, hundred thousand dollars to any science prize.

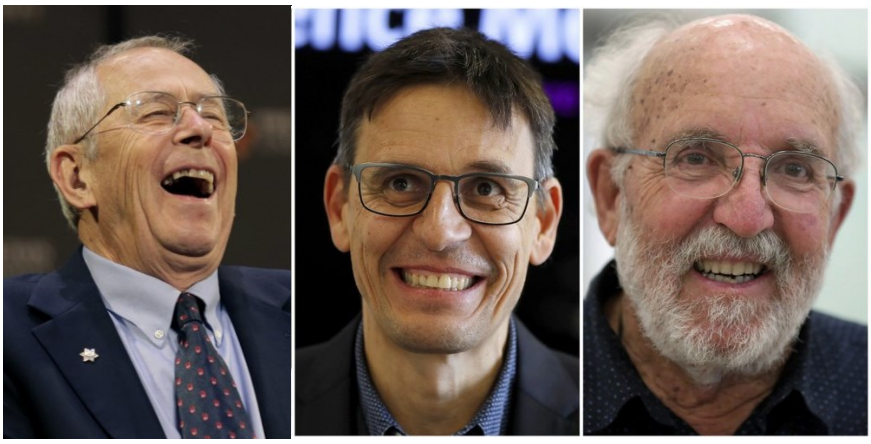
A collateral damaging effect of the excessive disproportion of the sums given to Nobel and Breakthrough Prize laureates is to give life to the myth of the lone genius; it gives the young generation the wrong and destructive idea that a very few of us have been blessed by some god with the gift of being incomparably more clever than the rest of us. By chance, I have had the good fortune during my career as a particle physicist to be close to many Nobel laureates and even to work together with five of them in different experiments: Carlo Rubbia, Jack Steinberger, Georges Charpak, Burton Richter and Jim Cronin. I have for them admiration and respect; their devotion to science, their intellectual and moral rigour, their determination to persevere in the effort in spite of difficulties and obstacles are an example for all of us. They are the exact opposite of a lone genius but for the young generation they are a much better model to follow: rather than hoping for being blessed by some god, they give them good reasons to work hard and progress.

When Yuri Millner faces such criticisms, he answers that he "*thinks that scientists should be much better appreciated, they should be modern celebrities, alongside athletes and entertainers. We want young people to get more excited. Maybe they will think of choosing a scientific path as opposed to other endeavours if we collectively celebrate them more*."

Sadly enough he may be right; the world we live in may have declined to such a level that only money can be considered worth of respect. Today, the only way to attract the young generation to science may be to have the hope for becoming rich dangled in front of them. When Donald Trump writes "*How to get rich*" it becomes immediately a bestseller. Let someone else write "*How to get honest*" or "*How to get generous*", nobody will read it. This is the world we live in and Viet Nam is not better than the rest of it; sadly, we are rather worse than average in this respect.

ASTROPHYSICS HONOURED BY THREE NEW NOBEL PRIZES[32]

This year again astrophysics has been honoured by the award of three Nobel Prizes[33]. One went to James Peebles, to reward an outstandingly rich life-long career as a cosmologist; the other two to Swiss astrophysicists Michel Mayor and Didier Queloz, for the first discovery, in 1995, of an extra-solar planet. Let us hope that this will help the Vietnamese authorities responsible for the management of science with becoming better conscious of the outstanding dynamism of this field of basic research and with being convinced of the importance to give it the strongest possible support.



Three happy Nobel laureates: from left to right Jim Peebles, Didier Queloz and Michel Mayor.

Peebles was born in Canada in 1935 but moved to Princeton in his mid-twenties and has been living there since that time. It is unusual that a Nobel Prize be awarded to honour the work of a whole life, I commented on that recently in these columns on the occasion of the award of the Breakthrough Prizes; it is interesting, and comforting, to see how well this seems to be received by the scientific community. Indeed, while Peebles is unanimously recognized as a pioneer of modern cosmology, one cannot name a contribution of his that stands out clearly above the rest of his work. When asked to mention one, he himself answered: "*I would be very hard-pressed to say. It's a life's work*." When he started working on cosmology, in the early sixties, he felt uneasy as well as excited because, he said, "*the long extrapolation from well-established laboratory results to the physics of our expanding universe was supported by exceedingly limited empirical evidence. I remember thinking I might complete two or three projects in this subject and then move on to something less speculative. That never happened because each project led to ideas for others, in a flow that was too interesting to resist.*"

In the first half of the past century, cosmology was still in infancy, a speculative field more than serious science. Peebles is a founding father of modern theoretical cosmology; he has laid much of its theoretical groundwork and pioneered many of the methods that have made it a predictive science that allows for testing its theories with observational data. His impact on students and colleagues, through his teaching and the famous textbooks that he wrote, is enormous. He reminds me of what Vicki Weisskopf was for nuclear and particle physics. Like him, generous to his students and colleagues, he is praised by all for being uncommonly thoughtful, gracious and kind.

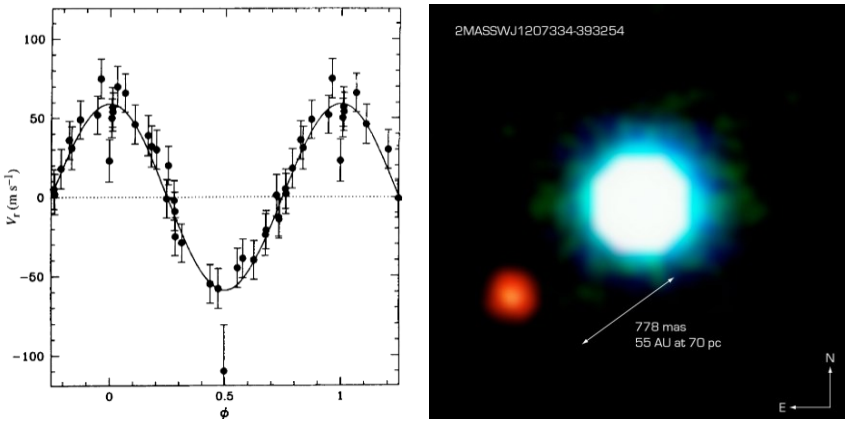
Over most of his lifetime, he focussed his curiosity on the very early Universe and its major puzzles: Big Bang, dark energy, inflation, dark matter, cosmic microwave background… In the past two decades, his interest drifted to more recent events related to the way in which galaxies form, with preference, as he says, on "*underappreciated issues*". In particular the fact that isolated galaxies are much

[32] Published in Tia Sang.
[33] See https://www.apnews.com/2695caa732944d789a121b2b23d124ce/gallery for beautiful pictures.

more common than isolated dark matter halos has been puzzling him. He justifies his new interest by saying "*What might we learn from lines of research that are off the beaten track? They check accepted ideas, always a good thing, and there is the chance Nature has prepared yet another surprise for us*".

Michel Mayor and Didier Queloz are two Swiss astrophysicists who published their discovery in Nature (November 1995, 378, 23). I was in Geneva at that time and I remember vividly the seminar that Michel Mayor gave at CERN. We were so proud and happy for them, a discovery made with a telescope of less than two metres in diameter when we were all talking about the 8 metre telescopes that ESO was building in La Silla and which started operation a bit over two years later. Kind of a victory of David over Goliath. We would not have imagined at that time that less than ten years later, the telescope in La Silla would take one of the very first pictures showing an extra-solar planet orbiting its star. And even less that by now over 4000 exoplanets have been discovered.

Mayor's and Queloz's work is a model of precision and rigour, their paper is a pleasure to read. In the direct legacy of the Swiss tradition of thorough watch making. They were measuring the Doppler shift of the star around which the planet is orbiting with a precision of only 50 km/h, the same as Jupiter is imprinting on our Sun. For half a year they measured the movement of several stars and found that only a small number of these show significant velocity variations. And although most candidates required additional measurements, they reported "*the discovery of a companion with a minimum mass of half Jupiter's mass, orbiting at 0.05 astronomical units (an astronomical unit is the radius of the Earth orbit around the Sun) around the solar-type star 51 Peg*". Their claim was substantiated by a beautiful sine wave fit to the observations and by a critical and rigorous review of other possible interpretations which they could exclude with reasonable confidence.



Left: the evidence for the wobbling movement of the star around which Mayor and Queloz discovered the first exoplanet. Right: direct observation, in 2004, using the Very Large Telescope of an exoplanet (reddish) orbiting a brown dwarf (white).

In April 2014, on his way back from a conference on exoplanets in Quy Nhon, Michel Mayor stopped by Ha Noi and gave a seminar at the University of Education. He is seen here together with Pham Ngoc Diep, who is now head of the Department of Astrophysics of the Vietnam National Space Center, translating his talk into Vietnamese.

To say that their discovery came as a surprise is both true and exaggerated. It is exaggerated in the sense that we knew enough at that time, and even decades before, to be confident that planets were present around many other stars. What would have been a major surprise would have been to give evidence for our Sun being the only star having planets. So big a surprise that nobody was seriously thinking of it as realistic. Yet, the discovery came as a surprise for two reasons: first because having searched for exoplanets for over a decade, one had taken the measure of the difficulty of the task and thought that it would take much more time before one could succeed; second, because one did not expect such a massive planet to orbit that close from its star.

Today, over 4000 exoplanets have been discovered using a number of different methods, the main one, in addition to that used by Mayor and Queloz, being the observation of the planet eclipsing the star when transiting in front of it. In the past century, we knew only about solar planets; the discovery of exoplanets has given a more complete and less biased picture of what the whole family of possible planets consists of. They have opened a new chapter in the study of how stars form from molecular clouds and how planets form in the disc of gas and dust that encircles them.

It would be unreasonable to think that of the billions of "habitable" planets that exist in the Milky Way, our galaxy, the Earth is the only place where life has ever appeared. Not to mention the billions of other galaxies that are known to populate the Universe. What we know of the chemistry that governs the synthesis of the basic molecules of life leaves no doubt about their presence on some other planets. And what we know of molecular and cell biology, even with major unanswered questions about the formation of the first cells and of the first pluri-cellular organisms, makes it reasonable to think that some form of life must have appeared on many of these. Chemistry and evolution offer such a rich arsenal to govern the genesis of life that we can dream of most fanciful and extravagant species filling our science-fiction universe. But it would not be reasonable to hope that we might eventually learn much more about these forms of life; they are too far away. It may be better this way. We can let our imagination ramble freely and dream of better lives on remote planets. Isn't it wonderful, after all, that we can simply close our eyes and invent a poem or a melody? Isn't it wonderful that we can simply close our eyes and forget for a while about crimes and wars, floods and quakes, jails and prisons, tears and blood, and about the tweets of Donald Trump?