Genes to Galaxies
35th Professor Harry Messel International Science School

From Light and Life to Genes and Galaxies
- 45 Years On

Chief Justice Robert French
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Forty five years ago, in 1964, I was one of two secondary school students from Western Australia who attended the precursor to this International Science School, namely the Nuclear Research Foundation Summer Science School at the University of Sydney. One of us from Western Australia went on to become a distinguished scientist. That was the other one. His name was Garth Illingworth. He was seriously clever. It was rumoured he had built his own nuclear magnetic resonance spectrometer in the school laboratory at Scotch College in Perth. He is Professor of Astronomy and Astrophysics at the University of California, Santa Cruz where he studies galaxy formation and evolution, quaintly called 'galaxy archaeology'.

Looking at Professor Illingworth's website to see what he has been up to in the last 45 years, I noticed that he has recently published papers about things called 'dropout galaxies'. What, I asked myself, is a dropout galaxy. Is it a galaxy which has had enough of the universe and has decided to go elsewhere or perhaps simply can't be bothered evolving any more? To avoid any suggestion of frivolity and since it may be relevant to a conference about genes and galaxies, I should inform you that my internet research tells me that very distant galaxies with very high redshifts are virtually dark at wavelengths shorter than the wavelength below which galactic and inter-galactic hydrogen absorbs light. That wavelength is 91.2 nanometres and is known as the 'Lyman limit'. In the 1990s researchers using the Hubble space telescope discovered galaxies with a redshift of about 3, some 12 billion light years away known as 'Lyman break galaxies'. They are virtually invisible in the ultraviolet spectrum. They are called 'dropout galaxies' because if you try to view them through the telescope in the ultraviolet frequency band, they drop out of sight. The effect is called the 'U-band dropout'. By testing for that feature, astronomers have found about a thousand Lyman break dropout galaxies.

Anyway, when I went for the scholarship interview for the 1964 Summer School I knew that I had no hope of matching Garth Illingworth. And I certainly didn't. Nevertheless, things turned out better than expected, although at one point in my interview they were not looking promising. I had been asked a question to which I gave a silly answer: 'What sound would you expect to hear in the vicinity of the very low frequency transmitters at the US base in North West Western Australia?' 'A low hum', I said. Well, maybe, if somebody were humming in the vicinity. But certainly not from the effect of electromagnetic radiation on my eardrums. What I thought was the low point became lower. The next question I was asked by the interview panel was:

How would you prove that the moon is not made of cheese?

This was a question which at the time I regarded as utterly unfair. No doubt it had something to do with the density of cheese and gravitational fields and tidal effects, none of which I had had much occasion to consider in the same string of thoughts. In fact I can't recall ever thinking about the possibility that the moon might be made of cheese. I was not able, in my own mind, to offer a quick convincing answer based on tides and the density of cheese. So I resorted to something my mathematics teachers had taught me at school, the reductio ad absurdum. That is to say, if you want to prove a theorem is true, it may be possible to do so by demonstrating that its falsity would lead to an absurd logical consequence. An analogous technique may be taken to demonstrate that a proposition is not true. So, taking a deep breath, I said something along the following lines:

Accepting the proposition that the moon is made of cheese requires acceptance of the existence of a cosmic cow. That would be a singularity and we do not get singularities in a rational universe.

Good answer – well it was then. Now, of course, we know, or at least have a strong working hypothesis, that the universe is littered with singularities in the form of black holes at the centre of many galaxies and a whole variety of other very odd things, including perhaps bits of superstring left over from the big bang. And how amenable is it ultimately to rational explanation within the limits of our thought processes. The quantum cosmologist and inflation theorist, Andrei Linde, has suggested that we live in a self-reproducing universe, a multiverse of inflationary domains or bubble universes budding off from each other. Couple this with the many world's interpretation of quantum mechanics under which every quantum transition which has occurred or is going to occur anywhere in the universe, generates a parallel universe for every possible outcome. Possible outcomes include improbable ones. In all this dizzying diversity could there not be a universe of cosmic cows and cheese moons. Anyway, my answer to the interview panel was sufficient unto the day. I secured the second scholarship and accompanied Garth Illingworth to the Summer School, which turned out to be the experience of a schooltime, if not a lifetime.

It began on 6 January 1964. There were 150 of us, secondary school students from all around Australia. It was the third Annual Nuclear Research Foundation Summer Science School for high school students.

The lectures were preceded by a passionate speech from the founder of the Summer School, Professor Harry Messel, Professor of Nuclear Physics at the University of Sydney. He was defending the new rather controversial Wyndham science education curriculum for secondary school students in New South Wales. The controversy is long dead, but I remember

Professor Messel holding up a large blue book, the new science textbook, and saying:

Show me a young man in ten years time who doesn't have a science education and I'll show you a young man who needs to be locked up for his own protection.

I don't know what was going to happen to the young women without a science education in ten years from 1964. Probably they would be looked after by the young men who had one.

There may have been a slightly sexist slip of the tongue in what Professor Messel said. But he can be forgiven for it. It was still relatively early in the sixties and there were quite a number of women students at the Summer School. Most of us would have had no idea of the controversy surrounding the introduction of the new science curriculum. But it was a good pointer to the reality that science operates in a wider world than the laboratory, a world inhabited by strong contending views on matters of policy where science is an inescapable part of the debate.

The 1964 Summer School was titled 'Light and Life in the Universe'. It was directed ultimately to the following topics:

- the units of living matter
- how life may have started on earth; and
- the possibility of life on other planets.

We began, however, with some basics in six lectures given by Professor Messel and Professor Stuart Butler, who was then Professor of Theoretical Physics at Sydney University. They took us first to the Rutherford Model of the atom, - negatively charged electrons drawn to look like ball bearings orbiting positively charged billiard ball nuclei for all the world like little solar systems. As they explained, this was a model with a big problem. According to Maxwell's theory of electromagnetism, an oscillating charge will continually radiate energy outwards in the electromagnetic field because oscillating motion involves acceleration. A negatively charged electron orbiting a positively charged nucleus is executing the equivalent of a simple harmonic oscillation and so should continually lose energy and spiral into the nucleus, like a satellite brought back to earth by loss of energy to upper atmospheric friction.

Plainly, this was not happening in reality. Moreover, observation indicated that electromagnetic radiation, including visible light, was emitted from excited atoms in discrete frequency bands or spectra. So we were introduced to Neils Bohr and the postulate that electrons occupy well-defined orbits from which they radiate energy very slowly or not at all. A change from a high energy orbit to a low energy orbit was accompanied by the emission of a packet of energy representing the difference between the two energy states.

But it was still ball bearings around billiard balls. All very classical. As the late, great American physicist, Richard Feynman, said:

Atoms are completely impossible from a classical point of view.

Something else had to be invoked to explain the stable states. We were then introduced to the words 'quantum mechanics'. We were told of Max Planck and the idea that oscillating charges or indeed any other physical system had discrete sets of possible energy values or levels and that the emission or absorption of radiation was associated with transitions between those levels.

We did not enter far upon the shifting sands of quantum theory which tells us that reality is a good deal less real than we might have thought by reason of our ability to sit on chairs and our inability to walk through walls. We did not explore the inherent indefiniteness of things at the smallest level, expressed in Heisenberg's uncertainty principle and the equation: $Dx.Dp = h$, where h is Planck's constant. We were not told that at the smallest scale the location and momentum of matter cannot be both determined with precision, nor its energy and place in time. Certainly, nobody mentioned that even when you extract the last micro electron volt of energy from a particle; it still jiggles with something called zero point energy reflecting the intractability of Heisenberg uncertainty and the probabilistic wave-like character of matter. We did not know that the properties of very small things are described by the probability that those things occupy particular states, whether they be of energy, or spin, or other properties, and that very small things may occupy more than one state. That uncertainty and the probabilistic nature of existence at the quantum level would have impacted upon our basic notions of causality and led us, if we had heard of it, to understand the force of Richard Feynman's statement:

A philosopher once said 'It is necessary for the very existence of science that the same conditions always produce the same results'. Well, they do not!

The assault on our sense of reality by exposure, particularly to the Copenhagen School of Quantum Theory, might have been too much for the young minds of 1964 to absorb in the course of a fortnight's lectures on the physics and chemistry of life. After all, even Einstein had rejected that school of thought as a 'weakening of the concept of reality'.

In any event, there was only so much time and many other wonders to follow as we heard from Professors Messel and Butler about gravitational fields, the origin of the solar system, the evolution of the sun and of the earth. Then, in lectures by Professor Ronald Bracewell of Stanford University, we were told of the possibility of life in other parts of the galaxy. Through Professor Martinas Ycas, we were introduced into the field of molecular biology and theories about the still mysterious origins of life on earth. He spoke of reason and purpose in biology and the idea of feedback mechanisms. He also spoke of the limits of science and of the personalities that construct science as 'of necessity outside science'. Embedded in that observation was a question to light up the brain cells. Does consciousness have anything to do with the way the universe works?

Professor Roger Penrose, Emeritus Rouse Ball Professor of Mathematics at Oxford and a collaborator with Stephen Hawking, has pointed to the centrality of the observer and therefore of consciousness in quantum theory. In his massive book published in 2004: The Road to Reality – A Complete Guide to the Laws of the Universe, he said1:

… it seems to me that a fundamental physical theory that lays claim to any kind of completeness at the deepest levels of physical phenomena must also have the potential to accommodate conscious mentality.

Quantum cosmologist, Andrei Linde, whom I mentioned earlier, has made the same point, when he said2:

Might it not turn out, with the further development of science, that the study of the universe and the study of consciousness will be inseparably linked, and that ultimate progress in the one will be impossible without progress in the other?

This puts me in mind of the 18th century Irish philosopher, George Berkeley, who developed the theory that things do not exist apart from the mind which perceives them. This led to a theological refutation in a famous limerick:

There was a young man who said 'God,
Must find it exceedingly odd
To think that the tree
Should continue to be
When there's no one about in the quad'.

REPLY:

'Dear Sir: Your astonishment's odd;
I am always about in the quad.
And that's why the tree
Will continue to be,
Since observed by, Yours faithfully, God'.

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[1] Penrose R, *The Road to Reality: A Complete Guide to the Laws of the Universe*, (2005) p 1033.

[2] Linde A, 'Inflationary Cosmology and the Question of Teleology' in Haught JF (ed), *Science and Religion in Search of Cosmic Purpose*, (Georgetown University Press, 2000) p 15.

The tree can be observed by any of you in the quadrangle at this University.

After Martinas Ycas' tantalising flirtation with 'mentality', with even a mention of 'soul' thrown in, we had Professor James Watson. Watson had shared the Nobel Prize for Physiology and Medicine with Francis Crick and Maurice Wilkins two years earlier in 1962. They won the prize for their determination of the complementary double-helix structure of the DNA molecule. In part, that determination was based upon a consideration of high quality x-ray diffraction studies of the molecule produced by Rosalind Franklin. It has not gone unnoticed that despite her contribution, she did not share in the Nobel Prize. Indeed, she was called, in a book about her life, the Dark Lady of DNA.

The x-ray diffraction studies involved directing short wavelength x-rays to DNA molecules. The x-rays would scatter off the atoms of the molecule in different ways and produce interference patterns which could be recorded and from which inferences could be drawn about its structure. The DNA pictures obtained by Franklin did not show a double-helix but showed a symmetric distribution pattern from which ultimately the double-helix structure was inferred.

The first thing that struck us about Professor Watson was not his Nobel Prize winning aura, but his appalling taste in ties. He wore a tie with a very strange, green, twisted pattern on it. This, he later revealed, was a reproduction of the RNA molecule with attendant ribosomes.

In his lectures, which were utterly engaging, Professor Watson introduced us to a molecular perspective on the living cell and the function of macromolecules within it. He identified as one of the key secrets of life the cell's capacity to synthesize the physiologically correct amount of specific proteins. This had to do with the ability to construct macromolecules by the linear linking of small molecules. Step-by-step he took us through these processes and the ways in which the structure of the fundamental molecule of organic life, the DNA molecule, was discerned.

The newspapers printed a story about Professor Watson. It turned out he could not spell. I seem to recall he had difficulty with the word 'potato'. This only made him more interesting to all the students. His lectures concluded with the presentation of a gift from Professor Messel for him to take home to the United States. I think it was a kangaroo skin.

The Summer School was then a peak experience for young, aspiring scientists and I have no doubt the same is true of the International Science School which has succeeded it.

After it was all over we scattered to the four corners of Australia to complete our last year of secondary education. In 1965 Garth Illingworth and I both enrolled in science at the University of Western Australia. He graduated with first class honours in physics and went on, as I have described, to consider, among other things, the birth and life of galaxies. I completed an undistinguished science degree, also majoring in physics. That is not to say that I was in anyway bored by it. I was particularly entranced by the things which were going on at the boundaries. The difficulty was that there was a lot of hard slog to cover the well-known terrain necessary to get there. And there were other interesting things happening on campus. The 1960s was a time of relative student activism and interest in a range of public issues, not least the Vietnam war and conscription. The same phenomenon was occurring in many other parts of the world. I became involved in student politics and public debates about these and other issues. Nevertheless I remember learning about forces and motion, statics and dynamics, electromagnetism, thermodynamics and quantum theory. There was a high mathematics content in the degree which introduced us to such mysteries as set theory, complex analysis and manifolds. I recall on an occasion listing to a 20 minute explanation of the proof of the theorem that an open ball is open. An open ball is a kind of set. Somebody asked for a simple explanation of what an open ball is. The lecturer responded – think of a balloon without a skin. That, of course, cleared it up for all of us.

We were taught physics in second year from the Feynman lectures. We were introduced to the famous Feynman diagrams which describe quantum electrodynamical interactions with straight lines representing fermions and wavy lines representing bosons. It was at this time that I discovered that a positron behaved exactly like an electron travelling backwards in time. It raised the possibility of effects preceding their causes. It also raised the possibility floated by John Wheeler that the whole universe of electrons was just one electron shuttling backwards and forwards in time. The difficulty with that possibility, as Feynman pointed out, was the imbalance of matter over antimatter.

Parts of the content of the science course that I studied have remained with me. I have tried to maintain a layman's interest in subsequent developments, particularly in physics and cosmology. But more importantly than the particular content of the courses, I learnt about scientific method and culture. And when the content has gone, it is the methodology that lingers on. It informs the world view, it expands horizons and consciousness and it informs thinking about issues in sometimes quite unrelated fields. Whatever one does afterwards, a science degree is never wasted.

My transition from physics to law was via a mathematical, symmetric, unitary group of dimension three, known as SU3 and something called the 'eightfold way'. Let me explain that rather cryptic statement.

In the early 1960s, particle physicists had discovered an increasing number of allegedly 'elementary' particles without understanding their relationships or underlying structure. The situation was a little like that with the discovery of new elements before the creation of the periodic table to explain their relationships. A large class of elementary particles is that known as hadrons. They are particles which participate in the strong interaction and, as was later discovered, are composed of quarks. Baryons and mesons were found in the early 1960s to fall into symmetric families of multiplets with the same spin and parity, but different mass, charge, baryon number and strangeness. It was then proposed by Professor Murray Gell-Mann at the California Institute of Technology and Professor Ne'eman at Imperial College, London, that there was an existing mathematical entity, a Lie group, which fitted the relationships between these particles. This was the symmetric unitary group of dimension three known as SU3. Gell-Mann called the new classification scheme the 'eightfold way'. This was based on Buddha's list of eight virtues that lead to the cessation of pain. There were eight relevant quantum numbers. When the classification scheme using SU3 was applied to known hadrons there was a gap in the decuplet group which had to be filled. The scheme required that the particle have negative charge with a spin of 3/2, positive parity, a mass of roughly 1,680 Million electron volts, a baryon number of +1, strangeness of -3 and apt to undergo stable to strong decay. In 1964 the predicted particle, the omega minus was found by physicists from Brookhaven using the 80" bubble chamber. Later the triplet set in the same group was used by Gell-Mann to predict the existence of quarks.

In my third and final year as a physics student, each of us was asked to present a seminar on a topic of our choice to our fellow students. Going for the boundary, I chose the eightfold way. I cannot remember now what I said about it. However, at the end of my presentation the Dean of Science said to me:

> You express yourself magnificently, but I am not sure you know what you are talking about.

On this basis I felt qualified and encouraged to enter the law. I should add, in the event that anybody wants to ask a question about this later, I am in no better position now to explain symmetric unitary groups than I was in 1967.

To study law after studying science is initially like entering a quicksand of imprecision. You leave the world of symbolic logic and the notations of mathematics, physics and chemistry and enter into a world of words. There are many words and frequently more words than are necessary to state the propositions which you are required to study. Sometimes the meaning of the propositions is embedded in the history of the law and is not discoverable simply by looking up a dictionary. But when you spend long enough studying the law and practising it, it is possible to warp the mind in such a way that it will read out the irrelevant and develop an intuition for legal argument and reasoning.

Much later, after graduating and practicing law and many years as a judge, I came to think of legal propositions or rules as fuzzy strings of logic with quantum-like properties. No matter how far you try to pin a word down to one particular precise definition, there is almost always a zero point jiggle, a freedom of movement in meaning – a nuance one way, a shade of meaning the other. Somehow, however, in the day-to-day dealings that people have in reliance upon the law and in the great bulk of ordinary litigation in the court, the uncertainties pass unnoticed just like quantum uncertainties in the macroscopic world.

When a question of law comes to court for the first time and there is dispute about its meaning, the court has to make interpretive choices according to well-established rules of interpretation and the choices it makes may affect the outcome. The court also has to make decisions about the facts of the case before it. It is perhaps useful at this point to briefly outline the process by which courts decide cases. The simple model of decision-making for a judge involves a kind of syllogistic logic:

1. Identify the rule of law applicable to the facts of the case. It might be something like this:

'If fact X exists, then result Y will be imposed'.

2. Determine what are the facts of the case based upon the evidence presented to the court. That is to say, decide whether fact X exists.

3. Apply the rule of law to the facts and, according to what the facts are, impose a result.

A practical example of this process is:

1. The rule of law – if you drive carelessly and damage someone's car, you must pay the cost of repairing it.

2. The facts found by the court – you have driven carelessly and damaged someone's car.

3. The result imposed by the court – you must pay the cost of repairing the car.

The rules of law under which we live are, for the most part, made by parliament and are found in Acts of parliament. Some of the rules of law are judge-made and have been developed over a long time through many cases. These include the rules for the formation and performance of contracts, and circumstances in which liability will be imposed for civil wrongs.

There are many laws made by parliament and they are frequently amended. Many of them are of considerable complexity. A court having to interpret a law for the first time often has to choose between one or more different meanings of the words used. It has to consider, in so doing, the purpose of the law and the context in which the particular words appear. The meaning of the words is not like a rock lying on the ground waiting to be picked up. The meaning given to a law by a court involves a process of construction by the court according to recognised rules.

Sometimes the court is required to decide whether or not certain conduct falls within very broadly expressed legal standards using words such as 'reasonable' or 'in good faith' or 'unconscionable'. In doing so it may make value judgments about whether the conduct was reasonable, or in good faith or unconscionable. I draw attention to these matters simply to make it clear to you that finding the correct answer in law is not always like solving a linear algebraic equation.

Against that background let me say something about science and the law. Legal cases arise out of disputes between people and/or companies and/or governments. They may be cases in which somebody is punished for a crime. They may be civil cases in which somebody is being sued. In many cases today, the process of finding the facts of the case may involve scientific evidence. It may be necessary for the court to consider scientific issues some relatively uncomplicated, some of considerable complexity. If there has been a car accident, expert witnesses may study skid marks and the distribution of damage and the location of the cars before and after the accident and offer inferences about how the accident occurred. In criminal cases, the identity of the offender may be proven by the use of DNA evidence. Expert testimony may be necessary to explain that evidence and its reliability to the court. In cases involving patents for inventions, the court may have to come to grips with quite complex scientific testimony. In 2007 I heard a case about a disputed technology for treating cancer using nano particles to transport low level radioactive isotopes and anti-cancer drugs to the site of liver tumours. One interesting aspect of the evidence concerned a variety of nano particle made of magnetic material which would be delivered to the site of the patient's tumour. The patient would then be placed in an externally applied rotating magnetic field. The point of putting the patient in the magnetic field was to heat up the particles in the vicinity of the tumour and so to try to kill it off. This depended upon the phenomenon of magnetic hysteresis. The magnetisation of the nano particles changed according to the changes in direction of the rotating field. Magnetisation did not quickly return to its initial state. This lag or hysteresis leads to the emission of heat energy. It is a phenomenon which applies to other kinds of physical system as well. Fortunately I had some recollection of it from my study of physics but it was well explained to the court by a retired physics professor.

As a young lawyer with some scientific education still fresh in my mind, I was always keen to take on cases which involved scientific questions. One such case, which I didn't win, involved a young man riding a motorbike who was clocked at twice the speed limit by a radar gun. He swore black and blue that he had only been travelling at the speed limit. The radar gun works by transmitting a radar beam at a certain frequency. When the beam hits a moving object in its path, it is reflected back and the Doppler Effect shifts its frequency upwards. The incoming beam is combined with the outgoing beam to produce a resultant frequency called the 'beat frequency' which is a function of velocity. According to that beat frequency the gun produces a read-out. I remembered from my physics that the speed of a wheel at the top is twice the speed at the axle. So, if the motorbike were travelling at a speed V, the spokes at the top of the wheel would be travelling at the speed 2V relative to an external observer. Could this be the explanation for the reading? Had some of the reflected beam come off spokes travelling at twice the speed limit even though the bike itself was travelling within the law? Could my client have been the telling the truth? I engaged the services of one of my former fellow physics students who was still doing his PhD. We brought to court a bicycle wheel, a radio frequency generator and a couple of oscilloscopes. The magistrate was absolutely transfixed by the evidence. But he didn't know a lot about physics. In the end, he side-stepped the physics completely and announced that he would rely upon the policeman's personal estimate of the speed. He convicted my client.

There were other cases involving scientific evidence. There were cases about the working of the breathalyser and the relationship between the concentration of alcohol vapour in the air breathed into the breathalyser and the concentration of alcohol in the blood which would determine whether the person being tested had committed an offence or not. There were related questions concerning the reliability of assumptions about the rate at which alcohol was absorbed into the blood following the last drink and eliminated from the blood thereafter. There was a case which went all the way to the High Court about the classification of the cannabis plant and whether it had one species or more than one species. And there was a case which I shall always remember which involved a simple demonstration of the way in which water comes out of a kettle with a stubby spout.

It is a delight to be here, 45 years after the Summer Science School of January 1964. Many of you, I hope, will go on to make careers in science. Some of you will contribute to our understanding of the world and the universe in which we live. Others may make contributions to dealing with the pressing problems which face humanity today and what is likely to be the multi-generational challenge of climate change.

For those of you who do not pursue a scientific career, may you never lose your sense of wonder and may you take into the world, whether it be the world of law or politics or business or public service or teaching or any other walk of life, a consciousness of the importance of science to our society and, beyond that, to our humanity.

There was a philosopher and mathematician of the 17th century whom I would like to quote to you by way of conclusion. His name was Blaise Pascal. He referred to man as the 'thinking reed'. He said:

Through space the universe grasps and engulfs me like a pinpoint; but through thought I can grasp it … All our dignity consists, therefore, of thought. It is from there that we must be lifted up and not from space and time, which we could never fill. So let us work on thinking well. That is the principle of morality.

Like much of what we find in scientific theory those thoughts offer us a provisional working hypothesis, probably incomplete, but worthy of our consideration.