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# The Figure and Legacy of Monseigneur Georges Lemaître

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At this Special Session on Cosmology on the occasion of the 50th anniversary of the death of Msgr Georges Lemaître, we sketch the scientific, historical and personal context behind his pioneering contributions to our modern theory of cosmology. This provides also, indirectly and from a particular angle, a certain understanding of his position and his actions as President of this Academy (1960-1966), where he found so much a home.

The history of modern cosmology can roughly be divided into six periods, which take us from the first explorations of Einstein's static universe starting in 1917 to the precision science we have today. Lemaître's contributions must be situated in the second, crucial period from 1927 to 1939 in which the basic framework of modern cosmology was developed.

Lemaître himself traces his interests in science and cosmology to his childhood years he spent in and around the city of Charleroi in the South of Belgium. Unfortunately, World War I intervened and, like so many of his contemporaries, Lemaître signed up to join the Belgian army to defend his country. After the War he entered the seminary for the priesthood and he was ordained as a priest in 1923.

In the seminary, Lemaître was granted special permission by Cardinal Mercier to study Relativity, Einstein's new theory of gravity. He wrote a dissertation on Einstein's new physics and his ideas on cosmology. On the basis of this work the Commission for Relief in Belgium, under the auspices of the American Educational Foundation, awarded Lemaître a fellowship to study abroad. That was the beginning of a unique scientific adventure.

He first went to the University of Cambridge where he deepened his knowledge of Relativity under the guidance of Lord Eddington, one of the foremost astronomers at the time. It is likely that the confluence of Eddington's interests both in the theory of Relativity and in astronomical observations has encouraged Lemaître to explore himself their intersection in his later work. Lemaître and Eddington had great admiration for each other. Later Eddington would write (in a letter to de Donder, Lemaître's mentor in Belgium) that he had found in Lemaître "a truly brilliant student, wonderfully quick and clear-sighted and of great mathematical ability". Coming from Eddington this really meant something!

In 1924 Lemaître went on to MIT and to the Harvard College Observatory to work with Shapley on Cepheids, variable stars. The timing of this visit was excellent because during that year the first observations which would challenge the age-old idea of an everlasting, static universe would be coming in. Lemaître was present e.g. at the celebrated 33rd meeting of the American Astronomical Society held in Washington in December 1924 where Russell announced Hubble's discovery that the great spiral nebulae are in fact other, distant galaxies. It is during this year that we also find Lemaître's first explorations of cosmology. He studied in particular the model of the universe proposed by the Dutch astronomer de Sitter – which incidentally was disguised as a static universe - and he showed, independently from Weyl, that in de Sitter's universe galaxies would recede from each other at a rate proportional to their separation. Starlight from distant galaxies would therefore be shifted to the red in de Sitter's universe, in line with the observational evidence at the time. But de Sitter's universe is empty, it contains neither galaxies nor observers! Therefore Lemaître abandons this model.

In July 1925 Lemaître returned to Belgium to take up a faculty position at the Catholic University of Louvain. He continued to think about cosmology, and wondered in particular whether Relativity could accommodate a universe that retains the appealing features of both Einstein's static universe and de Sitter's empty universe. A universe, in other words, that contains matter in the form of galaxies but at the same time exhibits the reddening of distant galaxies. Lemaître's stroke of genius then was to abandon the idea of a static universe. He did so in 1927 in a seminal paper *Un univers homogène de masse constante et de rayon croissant, rendant compte de la vitesse radiale des nébuleuses extragalactiques*, which he chose to publish in the Annales de la Société Scientifique de Bruxelles [G. Lemaître, 1927].

In this paper Lemaître first rediscovers Friedmann's equations that govern the evolution of a dynamical universe in Einstein's theory of Relativity. He then identifies a solution of those equations that describes an expanding universe interpolating between Einstein's static universe in the far past and de Sitter's empty universe in the distant future [cf Figure 1]. He shows further that if this were our universe then the expansion of space

would cause starlight from distant galaxies to be shifted to the red, as if the light were Doppler shifted by the motion of galaxies away from us. Lemaître derives (in equation (24) in [G. Lemaître, 1927]) what would later become known as the Hubble law; a linear relation between the rate of separation of distant galaxies and their distance away from us. Moreover, seeking observational corroboration or falsification for his prediction of a redshift, Lemaître takes Slipher's redshifts and Hubble's distances for a sample of 42 extra-galactic nebulae to estimate the proportionality constant $H$ in the distance-velocity relation. Because of the large uncertainties in the individual observations, particularly in the distances, Lemaître decides to divide the mean velocity by the mean distance in the sample, and in this way obtains the value $H$=575 km/s per Megaparsec.

In short, Lemaître establishes in this paper *the* fundamental connection between the theory of Relativity and cosmology. He himself once recalled, in his characteristic light, humble style, that "I happened to be more mathematician than most astronomers, and more astronomer than most mathematicians".

However, most of the important figures in cosmology hardly took notice of Lemaître's groundbreaking work, and the few remarks that did reach Lemaître, were actually mostly negative. In the margin of the 1927 Solvay Conference, for instance, Lemaître had a brief discussion of his work with Einstein, who concluded this by saying "Your calculations, Monsieur Lemaître, are correct, but your physical insight is *tout à fait abominable*". Clearly the scientific community was not (yet) prepared to abandon the ancient, cherished idea of an eternal, static universe.

But in 1929, Hubble established observationally a linear distance-velocity relation for the spiral nebulae. Using more precise observations of 24 distant extra-galactic nebulae obtained with the 100-inch telescope on Mt Wilson, the most powerful telescope at the time, Hubble obtained a proportionality constant of 513 km/s per Megaparec – not very different from the value found by Lemaître two years earlier. Hubble's work made no mention of the expansion of the universe. Instead he interpreted his observations in terms of a usual Doppler shift. But the scientific community recognised the potentially far-reaching implications of Hubble's observations and in particular the need to reconcile these with Relativity if the latter were to provide a viable theoretical framework for cosmology.

The problem of the reddening of distant nebulae was therefore high on the agenda at the London meeting of the Royal Astronomical Society on Friday, 10 January 1930, where Eddington famously said "We ought to put a little motion into Einstein's world of inert matter, or a little matter in de Sitter's primum mobile". Georges Lemaître was not present at this meeting, but when he read its proceedings in *The Observatory* a few weeks later he responded and reminded Eddington that two years before he had already found the intermediate, expanding solution that he and de Sitter were now looking for [cf Figure 2]. Lemaître also enclosed several copies of his original paper with his letter and asked Eddington to give one to de Sitter.

Eddington confessed that, although he had seen Lemaître's pioneering paper at the time, he had failed to realise its far-reaching consequences and he had forgotten about it until that moment. Around the same time Eddington himself independently showed that Einstein's static universe is unstable to either expansion or contraction. He was thus ready to adopt Lemaître's model of 1927, which became known as the Eddington - Lemaître universe.

Starting in May 1930 both Eddington and de Sitter generously recognised Lemaître's major discovery in their publications, and they enthusiastically supported and disseminated the new concept of an expanding universe. In 1931, in an extraordinary sign of appreciation that shows the importance he attached to Lemaître's work, Eddington ordered a translation of Lemaître's original paper to be published in the widely read Monthly Notices of the Royal Astronomical Society (MNRAS) [G. Lemaître, 1931].

But then something seemingly odd happened. The section in the original paper where Lemaître derives the 'Hubble constant' $H$ was omitted in the translation, and replaced by a short note referring to 'available data'. This has led some historians to suggest Lemaître had been censored – perhaps even to advance Hubble's reputation?

However the case was settled in 2010 thanks to a careful investigation by Livio, who found in the archives of the Royal Astronomical Society a letter from Lemaître to Smart, the editor of the MNRAS, in which Lemaître writes that "he did not find advisable to reprint his provisional discussion of radial velocities". Lemaître's motivation to leave out this particular section was most likely that the uncertain observational material available in 1927, which nevertheless convinced him of the validity of his theoretically derived 'Hubble law', had by 1931 been superseded by better data from Hubble and Humason. And, of course, Lemaître was not interested in self-promotion.

The translation of Lemaître's article in the MNRAS had a large impact, and his idea of an expanding, evolving universe rapidly became the central pillar of modern relativistic cosmology. Finally also Einstein came around. In the short article in which he accepted the expanding universe Einstein also discarded the idea of a cosmological constant, which he had introduced in his equations in 1917 to make possible a static universe. In a letter to

Tolman he wrote “Dies ist wirklich unvergleichlich befriedigender”, referring to his theory of Relativity without the cosmological constant term.

Interestingly Lemaître had a rather different view on the cosmological constant. Lemaître regarded this as a physical substance, known today as dark energy. Consequently ‘little lambda’ (as the cosmological constant was referred to at the time) featured prominently in Lemaître’s work on cosmology. The first known representations of an expanding universe, made by Lemaître around 1928, clearly illustrate this [cf Figure 3]. Around 1931 Lemaître settled on what he called a ‘hesitating’ universe. This is a universe which initially expands fast, then slows down so that large-scale structures such as stars and galaxies can form, and finally accelerates again, driven by the effect of a dark energy component. Being much more than Einstein guided in his work by observations, Lemaître was led to the idea of a ‘hesitating’ universe with a cosmological constant, because the large value of the Hubble constant which he and Hubble had found, implied there had to be a preceding era of slower expansion in order for the universe to be old enough to harbour stars and galaxies at least as old as planet Earth. He maintained this vision of cosmological evolution – which is in excellent agreement with present-day precision observations – for the rest of his life.

Lemaître’s hesitating universe also introduces a profoundly new feature in his cosmology: it replaces the nearly static phase in the far past of his original model of 1927 with a genuine origin. He referred to the state at the beginning as a primeval atom. (The term Big Bang was coined much later by Fred Hoyle). By boldly proposing the world had a beginning Lemaître made it clear that a universe in expansion may well have been in a radically different physical state in the far past. The notion of a cosmic evolution is central in Lemaître’s thinking. He explained his view in what is perhaps his most visionary article *The Beginning of the World from the Point of View of Quantum Theory*, published in *Nature* in 1931 [G. Lemaître, 1931b]. In this short paper he argues, to my knowledge for the very first time in the history of modern cosmology, that our universe had an origin which should be part of science, governed by physical laws we can discover. It is a beautiful, almost poetic paper in which Lemaître explores from a purely physical viewpoint how our universe could have come into existence - a question that would become one of the central research topics in the fields of quantum gravity and quantum cosmology more than half a century later.

Of course Lemaître did not put forward a theory or even a model for his primeval atom. In Relativity the origin of an expanding universe is a spacetime singularity where our usual notions of space and time cease to be meaningful, and Einstein’s theory breaks down. Lemaître realised this, but suggested space and time emerged from a more fundamental, abstract quantum mechanical state which, he argued, stands prior to space-time. In line with this view he regarded the beginning as a kind of horizon beyond which lies a realm of reality that neither influences our observable universe nor will ever be accessible to our observations. In a sense Lemaître’s primeval atom acts as a boundary between physics, and metaphysics.

Incidentally Lemaître was led to consider a quantum origin of the world partly because he thought there should be a ‘natural’ beginning, and he reasoned that the indeterminacy of quantum theory could provide a potential mechanism to generate a complex universe from a set of elegant and simple initial conditions. Today this idea is realised concretely in inflationary cosmology where the rapid expansion transforms the simplest initial state – the quantum vacuum – into the seeds of the complex configuration of large-scale structures we find in today’s universe.

Lemaître realised however that a fuzzy quantum origin does not give rise to a unique world. Contemplating the implications of this, he wrote “Clearly the initial quantum could not conceal in itself the whole course of evolution. The story of the world need not have been written down in the first quantum like the song on a disc of a phonograph ... Instead from the same beginning widely different universes could have evolved” [G. Lemaître, 1931b] – a worldview not unlike what today we call the multiverse.

In the light of Einstein’s reluctance to accept cosmic evolution it will come as no surprise that he was not happy with Lemaître’s hypothesis of a primeval atom. Ironically he even complained to the Belgian priest that this reminded him too much of Christian dogma, whereas Lemaître was making the case for a scientific inquiry of the universe’s origin.

Despite their differences, however, in the early 1930s Lemaître and Einstein interacted frequently with each other. Their discussions were friendly and stimulating. During these years Lemaître spent several terms in the United States, where he wrote a number of highly influential articles in which we find the seeds of many of the ideas that later became part of the standard model of relativistic cosmology. These include the construction, inspired by Tolman’s work, of the first (spherical) models of the formation of galaxies in an expanding universe, and an interpretation of the cosmological constant as a vacuum energy. In response to a question from Einstein, Lemaître also demonstrated that under certain conditions a beginning of time is unavoidable in Relativity. This result would be proven in full generality by Hawking and Penrose only in the 1960s, and it emphasises the quantum mechanical nature of Lemaître’s primeval atom. Finally in 1934, he suggested there should exist fossil

relics of the hot dense state of the universe at early times, which might allow us to trace back our history and “reconstruct the vanished burst of formation of the worlds” as he put it.

Meanwhile Lemaître had become the darling of the American press. The public discovered to its amazement that the ‘father of the big bang’ was also a Catholic priest. Lemaître, however, patiently explained why he saw no conflict between what he called ‘the two paths to truth’ that he decided, at a very young age, to follow. “Once you realise”, he argued, “the Bible does not purport to be a textbook on science, and once you realise Relativity is irrelevant for salvation, the old conflict between science and religion disappears”. [cf Figure 4]

Lemaître carefully maintained a clear distinction between science and religion throughout all his life, respecting meticulously the differences in methodology and language between both. Far from the concordist interpretations that sought to derive the truths of faith from scientific results Lemaître insisted that science and religion have their own autonomy. He set out his position clearly and eloquently in his rapporteur talk at the Solvay Conference on Astrophysics in 1958 in which he emphasized once more that the hot big bang model is nothing but a scientific hypothesis, to be verified or falsified by observations, which remains entirely outside the realm of metaphysics or religion.

Consequently, Lemaître was not amused with the *Un’Ora* address of Pope Pius XII to this Academy in 1951, in which the Pope suggested that modern cosmology gives credit to the doctrine of *ex nihilo* creation at the beginning of time (without, however, explicitly referring to Lemaître’s work). In the early 1960s Monsignor Lemaître, as President of the Pontifical Academy of Sciences, would strive to maintain the autonomy of the Academy to avoid any such mixing of science and theology. His methodological purity put him in an excellent position to advance the Academy’s goals of fostering excellent science while maintaining a healthy relation with the Church.

Does this mean that in Lemaître’s view cosmology has absolutely no meaning for philosophy or theology, or vice versa? Not exactly. Lemaître himself certainly experienced a deep unity between his spiritual and professional life, and I am tempted to think that the harmonious coexistence of his cosmology and his faith, not at a conceptual level but rather through his actions and initiatives, may well have been an important source of inspiration and creativity that led him to conceive of a universe in evolution, with an origin. We can find a hint of such a unity in the last paragraph of the manuscript of the article [G. Lemaître, 1931b] -–– crossed out before publication – in which he put forward his ‘primeval atom’ hypothesis. In this, he writes “I think that everyone who believes in a supreme being supporting every being and every acting, believes also that God is essentially hidden and may be glad to see how present physics provides a veil hiding the creation”. Indeed a constant theme in Lemaître’s theology was Isaiahs notion of Deus Absconditus. A hidden God, hidden even at the beginning of the world. Lemaître’s physical description of the emergence of space and time from a primeval quantum respects the transcendence of God and, correspondingly, the autonomy of the world.

When the second World War engulfed the continent Lemaître stayed in Belgium where he focused on the needs of his students and tried to comfort his family and friends. During this period he was cut off from his international contacts and became scientifically isolated. He did not participate in the further development of the big bang model after the war, leading e.g. to Alpher’s and Gamov’s understanding of primordial nucleosynthesis and to the prediction by Alpher and Hermann of a thermal relic radiation of the hot big bang. Instead, Lemaître devoted most of his time to numerical computation, an old passion of him dating back at least to his time at MIT in the late 1920s. He famously called upon his students to carry a Burroughs E101 (one of the first electronic computing machines) which he had seen at the World Expo in Brussels in 1958, up to the attic of the physics building in Leuven, thereby establishing the university’s first computing centre.

But observations that could vindicate Lemaître’s hot big bang hypothesis remained elusive even in the 1950s. In those years his cosmology was actually not seldom regarded as old fashioned science that had been pursued in a spirit of concordism, his critics would say, and a rival theory, the steady state model of Bondi, Gold and Hoyle, entered the stage.

Lemaître’s fortunes turned around in 1964 with the discovery of the cosmic microwave background by Penzias and Wilson and its cosmological interpretation by Dicke, Peebles, Roll and Wilkinson as remnant radiation of a hot Big Bang. Lemaître heard about this discovery on the 17th of June in 1966, a mere three days before his death, in the hospital, where a close friend brought him the news that the fossil relics that prove his theory right had finally been found. Lemaître replied ‘Je suis content... maintenant on a la preuve’.

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