Jayme Tiomno – 50 Years of Brazilian Physics

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Abstract

Jayme Tiomno was an eminent Brazilian theoretical physicist whose career spanned over 50 years from the mid-1940's onward. He and his physicist wife, *Elisa Frota-Pessôa*, were together active in teaching and in establishing infrastructure and environments for fundamental physics research in Brazil, as well as in their own research areas.

Tiomno's work in the second half of the 20th century touches on the most important themes in fundamental theoretical physics, and it was his ambition to both carry out research in fundamental physics and to educate his students to continue the work, while setting up the institutions in Brazil to support them.

Apart from many more specialized topics, these comprise three major themes: (1) *Particle physics*; (2) *Gravitation*, relativity, cosmology and relativistic astrophysics; and (3) Fundamentals and interpretation of *quantum mechanics* (and its eventual combination with gravitation: *quantum gravity*). We give a brief history of each of these themes as an introduction to Tiomno's later works, followed by a summary of his most important contributions, his efforts in founding and implementing institutions for physics research in Brazil and elsewhere, and his collaborations with many prominent physicists, in Brazil and abroad.

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I. Introduction

Jayme Tiomno was born in Rio de Janeiro on April 16, 1920, the son of Russian-Jewish immigrants who had arrived in Brazil about 10 years earlier. There was nothing in his background that might suggest that he would become an eminent theoretical physicist. But his parents both valued education and saw to it that he and his siblings (an older brother, a twin sister, and two younger sisters) were all able to attend college. In the year of his birth, on Sept. 7, the Brazilian national holiday, the *Universidade do Rio de Janeiro* (URJ) was founded as the first real university in Brazil (as a collection of faculties and institutes combined from existing institutions).

After his childhood and youth spent in small cities in *Minas Gerais*, Tiomno's family returned in 1934 to Rio, where Jayme completed his *curso complementar* in medicine and then began studying medicine in 1938 at the *Universidade do Brazil* (UB – as the URJ was now called). In early 1939, Jayme was enrolled by his brother for Natural History at the *Universidade do Distrito Federal* (UDF), a newer research university founded in the capital in 1935 by *Anisio Teixeira*, an eminent educator who was at the time Director of Education of the Federal District. Tiomno qualified for the physics course, but was unable to study at the UDF because it was closed by the Vargas regime. Its physics curriculum was incorporated into the *Faculdade Nacional de Filosofia* (FNFi) and moved to the UB. Tiomno later had to decide between medicine and physics, and he chose the latter, graduating in 1941.

Tiomno entered military service, and was able to do some research with his mentor, the experimentalist *Joaquim da Costa Ribeiro*, and complete his *licenciatura* during the War. However, his real interest lay in theory, inspired by his Italian professor of theoretical physics, *Luigi Sobrero*, and after the War, he obtained a fellowship to do graduate research at the *Universidade de São Paulo* (USP), in the department founded by *Gleb Wataghin*, under Wataghin's star pupil, the theoretician *Mario Schenberg*.

The teaching staff in physics at the FNFi, 1942. From left: *Paulo Alcântara Gomes*, *Elisa Frota-Pessôa, Jayme Tiomno, Joaquim da Costa Ribeiro, Luigi Sobrero, Leopoldo Nachbin, José Leite Lopes,* and *Mauricio Matos Peixoto*.

Tiomno spent most of 1946 at USP, studying hard to catch up in modern physics, to which he had hardly been exposed at the FNFi. He also met *César Lattes*, a younger physicist and a rising star who went early that year to Bristol, England, to work with *Cecil Powell* and *Giuseppe Occhalini*, using photographic emulsions to detect cosmic-ray particles. Lattes improved the emulsions and the three were able to detect the *pion*, which had been predicted by *Hideki Yukawa* in 1935, and was the first true meson to be observed. In 1948, Lattes went on to Berkeley, where he and *Eugene Gardner* detected artificially-produced pions from the 184“ cyclotron for the first time. Lattes, at 24, became a scientific hero, especially in Brazil.

César Lattes and *José Leite Lopes,* about 1950.

Tiomno in the meantime returned to Rio in early 1947, but was then offered an assistantship with *Mario Schenberg* at USP, where he went in mid-year of 1947. He worked with Schenberg on formulating General Relativity (GR) in Minkowski space, his introduction to GR. The project was completed but never published.

Tiomno's return to USP in mid-1947 marks the real beginning of his research career, and also the beginning of a lifelong relationship with his later wife, *Elisa Frota-Pessôa.* She had been his fellow student and colleague at the FNFi. She had married early, to the physiologist and biologist *Oswaldo Frota-Pessôa*, and had two children: Sonia (born 1942) and Roberto (born 1944). But she and Oswaldo had separated by 1946, and when Jayme Tiomno returned to Rio in early 1947, they began an intimate relationship. Both shared their ideals of performing significant physics research and establishing institutions for education and research in Brazil. Their young colleagues *José Leite Lopes* and *César Lattes* also shared those ideals, and they became part of the '*founders generation*' for Brazilian physics. In late 1947, Tiomno, on the recommendations of Schenberg and Leite Lopes, was granted a fellowship for graduate work at Princeton by the U.S. State Department.

He had to leave Brazil abruptly in early February, 1948 to meet the starting deadline for his fellowship. In Princeton, he joined the group of *John Archibald Wheeler*, already a well-known theoretician, working in nuclear and particle physics. Nevertheless, Wheeler started Tiomno on a project involving *point particles in GR* and their (gravitational) radiative damping. Tiomno was frustrated with the project and received little help from Wheeler (and from Einstein). But his interest in the pion → muon decay chain had been aroused by a seminar given by Lattes at USP, and he independently conceived the ideas of separate ***weak*** and ***strong interactions*** and a '***universal Fermi interaction***' (UFI) to describe the former. He mentioned these ideas to Wheeler, who was very interested, and they collaborated intensely for a year (June 1948 – June 1949), publishing 5 significant papers on meson physics.

This became Tiomno's Masters' thesis. When Wheeler left on sabbatical in June, 1949, Tiomno, with his fresh MSc degree, collaborated with *Chen Ning Yang* and *David Bohm* on weak-interactions physics and on relativistic quantum mechanics. He then began his PhD thesis work with *Eugene Wigner* as mentor. He finished his thesis in Sept. 1950 and returned to São Paulo on October 10. We shall hear more about his thesis work below. At Princeton, Tiomno also met *Richard P. Feynman* and *Cécile Morette*, and invited both to visit the newly-founded ***Centro Brasileiro de Pesquisas Físicas*** (CBPF) in Rio, which he had helped to plan and implement.

When Tiomno returned to USP in late 1950, he was excited by three passions: His desire to contribute to fundamental physics, his hope of establishing physics education and research in Brazil, and his love for Elisa. They guided his efforts in the following years.

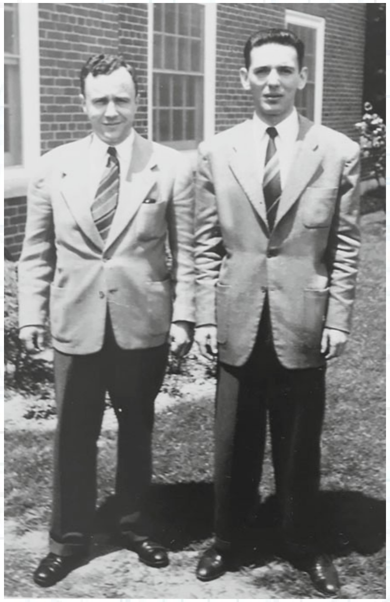
Suggested reading:

Silvia Tiomno Tolmasquim, '*Histórias de invernos e verões*', *Verve*, Rio de Janeiro (2014); ISBN 978-85-66031-77-5. A history of the Tiomno and Aizen families.

José Maria Filardo Bassalo and Olival Freire Jr., '*Wheeler, Tiomno, e a Física Brasileira*', in *Revista Brasileira de Ensino de Física*, Vol. 25, No. 4, p. 426 (2003).

Karin S.F. Fornazier and Antonio A.P. Videira, '*Os anos de formacão de um físico teórico brasileiro: Jayme Tiomno entre 1942 e 1950*', in *Ciência e Sociedade*, CBPF, Vol. 5, No. 1, pp. 1–12 (2018).

Princeton, 1948–50



Upper left: Wheeler and Tiomno, Princeton, summer 1948.

Upper right: At the AAAS meeting in Washington/DC, Sept. 1948. *Seated*: Lattes, Wheeler; *standing*: Tiomno, Willis Lamb, Isidor I. Rabi.

Lower left: A meeting in Princeton, March 1949. ***Front, kneeling***: Hervasio de Carvalho, José Leite Lopes, Jayme Tiomno; ***standing behind****:* César Lattes, Hideki Yukawa, Walter Schützer.

Lower right: Tiomno after receiving his MSc degree, Princeton, June 1949.

II. Themes in 20th century physics

Jayme Tiomno's work in the second half of the 20th century spans the most important themes in fundamental theoretical physics; it was his ambition to do relevant research in fundamental physics and to educate his students to continue the work, while setting up the infrastructure in Brazil to support them. Apart from many more specialized topics, these comprise *three major themes*, which were intertwined throughout the century:

(1) *Particle physics*; (2) *Gravitation*, relativity, cosmology and relativistic astro-physics; and (3) Fundamentals and interpretation of *quantum mechanics* (and its eventual combination with gravitation: *quantum gravity*). We give a brief history of each of these themes as an introduction to Tiomno's later works.

1. ***Particle physics*** dates from the discovery of the first elementary particle, the ***electron***, by J.J. Thompson, Philipp Lenard and others in the mid-1890's. The term '*electron*' was suggested later by Fitzgerald, Larmor and Lorentz. This discovery also marks the observation of the *quantum of electric charge*, e_0 (R.A. Millikan, 1909). The second elementary particle to be found was the ***photon***, the quantum of light and 'messenger particle' of the electromagnetic force. Its existence was suggested by the work of Max Planck on thermal or 'black body' radiation (1900), and was substantiated by Einstein's treatment of the photoelectric effect (1905) and by A.H. Compton ('*Compton effect*', 1923). The name 'photon' was coined by the physical chemist G.N. Lewis in 1926. The third 'elementary particle' was the ***proton***, the nucleus of the lightest atom, *hydrogen*; it was definitively identified by Ernest Rutherford in nuclear scattering experiments in 1919, and named by him in 1920.

During the 1920's, it became clear that atomic nuclei could not be correctly described by only the two particles, p^+ and e^- (proton and electron). Rutherford suggested the existence of a *heavy* particle, like the proton, but without electric charge; the ***neutron*** was observed by *James Chadwick* in England and by the *Joliot-Curies* in France in 1932. It is slightly more massive than the proton. Two years earlier, *Wolfgang Pauli* had proposed a *light* neutral particle which would accompany the emitted electrons in nuclear ß decay, thus rescuing the conservation of energy and momentum in those decays. He originally termed it the 'neutron', also; but *Enrico Fermi* later suggested the name '***neutrino***', since it is small and light.

'***The Radioactives***' at a meeting in 1932. They had recently received Pauli's note suggesting a new particle, the *neutrino*. ***From left***: James Chadwick, George de Hevesey, Frau Geiger, Hans Geiger, Lise Meitner, Ernest Rutherford, Otto Hahn, Stefan Meyer, Karl Przibram.

Around 1928, based on *P.A.M. Dirac*'s theory of the relativistic electron, the anti-electron or '***positron***' was suggested and soon found (in 1932 by *C.D. Anderson* at Caltech, and by *Patrick Blackett* and *Giuseppe Occhialini* in Cambridge). Finally, two particles of intermediate mass (so-called *mesons*) were suggested/ discovered in the mid 1930's: the *pi meson* or '***pion***' was proposed by *Hideki Yukawa* in 1935, from his theory of the nuclear binding force (in analogy to the electromagnetic force). It would be the 'messenger' particle of the nuclear force (later attributed to the *strong interaction*). And the following year, a particle of intermediate mass, the *mesotron* or '***muon***', was detected as a cosmic-ray product by C.D. Anderson and Seth Neddermeyer. Thus by the late 1930's, a total of 8 'elementary' particles were known or proposed. (Three of them, the *nucleons* (proton and neutron) and the *pion*, are now classed as *composite* particles and are thus not 'elementary').

This was still the situation in 1947, since basic research had been interrupted by the War. The neutrino and the pion had still not been observed experimentally, and the nature of the 'mesons' (muon and pion) and their relation to each other was still unclear. Jayme Tiomno took up the task of understanding these particles and the forces that affect them while still at USP in late 1947, and it occupied him for the next 15 years and more.

Suggested reading:

Claude Amsler, *'Nuclear and Particle Physics'*, IOP Publishers (2015); ISBN 978-0-7503-1141-0.

John Campbell, Joey Huston, and Frank Krauss, '*The Black Book of Quantum Chromodynamics – A Primer for the LHC Era*', Oxford University Press (2018); ISBN 978-0-19-965274-0.

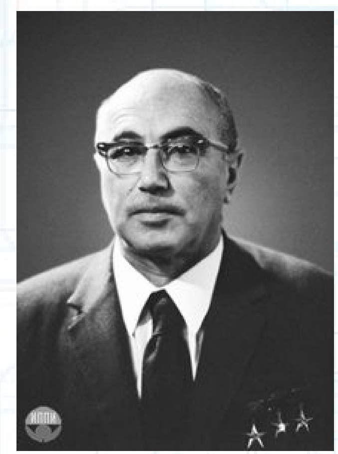
Abraham Pais, '*Inward Bound: Of matter and forces in the physical world*'. Clarendon Press/Oxford University Press (1986); ISBN 0-19-851997-4. A history of particle physics (with some other topics) by a participant who knew all the major players.

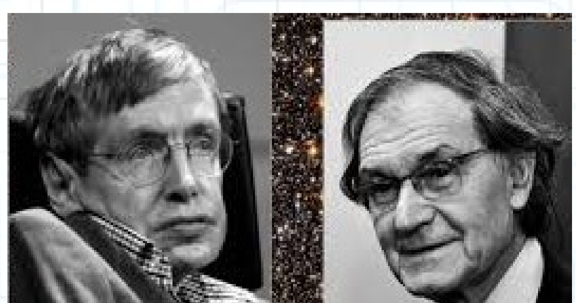
2. Modern ***gravitational physics*** dates from the early 20th century. Lorentz, Poincaré, Fitzgerald and others had speculated about applying the *principle of relativity* to electromagnetism (Maxwell theory). Albert Einstein realized the significance of those speculations and formulated his *Special Relativity* in 1905. Ten years later, with the help of *Marcel Grossmann* and *Michele Besso*, he completed his *General Theory of Relativity* (GR), the modern theory of gravitation. After the early period from 1915–1925, when solutions to Einstein's field equations were found (e.g. by *K. Schwarzschild*, 1916: gravitational singularity; *A. Einstein*, 1917: closed, static universe; *W. de Sitter*, 1917: zero-density universe; *A. Friedmann*, *G. Lemâitre*, 1924/27: expanding universe), Einstein began working on a unified theory of gravity and electromagnetism, and active work on GR decreased after about 1928.

In the period 1935–1955, Einstein published with *N. Rosen, L. Infeld, B. Hoffmann, P. Bergmann, W. Pauli, V. Bargmann*, and *E.G. Strauss* on some details of GR theory, and some other authors – notably *J.R. Oppenheimer et al*. (1939: collapse of stellar remnants) and *K. Gödel* (1949: static rotating universe with timelike loops) also made important contributions. But only in the early 1950's did the 'great revival' of GR and its applications to relativistic astrophysics and cosmology begin, stimulated initially by *J.A. Wheeler* and his school (Princeton, Univ. Maryland, Caltech), and independently by *Bryce deWitt* and *Cécile Morette deWitt* (Univ. North Carolina, Univ. Texas), and in England by *D.W. Sciama, C. Isham, R. Penrose,* and *S. Hawking* (in London and Cambridge), and in the USSR by *Y. Zel'dovitch, I. Novikov*, and *R. Sunyaev*.

They and their coworkers were responsible for the '*golden age of relativistic astrophysics*' from 1960–1970, and its continued development by a younger generation, encouraged by observational and experimental successes (discoveries of *quasars*, *pulsars*, the *cosmic microwave background* (CMB); indirect (1974) and direct (2015) observation of *gravitational waves*; indirect (1995) and direct (2019) observation of *black holes; dark matter*, *dark energy*, etc.). Several conference series were begun in the late 1950's, the 60's and 70's, some of them attended by Tiomno, and Tiomno started working in this field while still a graduate student (before Wheeler did, in fact), and continued to make contributions throughout his career, especially after his second Princeton stay, as we shall see.

Above left: Wheeler, Misner, Thorne; ***Below left***: Bryce and Cécile DeWitt; ***Below center***: Stephen Hawking and Roger Penrose; ***Below right***: Yakov Zel'dovitch.





Suggested reading:

Abraham Pais, '*Subtle is the Lord... The Science and the Life of Albert Einstein*'. Oxford University Press (1982); ISBN 0-19-853907-X.

Lee Smolin, '*Three Roads to Quantum Gravity*'. Basic Books, New York (2001); ISBN 978-0-46507-835-6.

Cécile Morette deWitt, '*The Pursuit of Quantum Gravity*'. Springer, Berlin (2011); ISBN-13: 978-3-64214-269-7.

Kip S. Thorne, '*Black Holes and Time Warps. Einstein's outrageous legacy*'. W.W. Norton, London (1994); ISBN 0-393-31276-3.

Charles W. Misner, Kip S. Thorne and John A. Wheeler, '*Gravitation*', Princeton University Press (1973–2017); ISBN 978-0-691-17779-3.

3. ***Quantum theory*** dates from *Max Planck*'s theory of *black-body radiation* in 1900. Planck found evidence for the *quantization of energy* (light: *photons*) but held it to be merely a mathematical convenience for formulating his theory. *Einstein* (1905) proposed the reality of the photon in his theory of the *photoelectric effect* (Nobel prize 1922), and it was later confirmed by many observations. Einstein himself contributed to the 'old quantum theory' up to about 1925 (derivation of Planck radiation, quantum statistics, electron spin) but was unconvinced by its modern formulation in the last 30 years of his life.

Niels Bohr applied the quantum principle to *Rutherford*'s *nuclear model* and successfully described the hydrogen atom, with later improvements by *A. Sommerfeld*. This theory had many limitations, which were overcome in 1924–1928 by *W. Heisenberg, M. Born, P. Jordan, N. Bohr, E. Schrödinger, P.A.M. Dirac* and others, leading to the ***Copenhagen Interpretation*** (*Born, Bohr, von Neumann*). It became 'accepted doctrine', giving rise to the 'Shut up and calculate!' period from around 1930–1955. Some progress was made in this time (quantum field theory, especially quantum electrodynamics (QED)), but the period was in the main a time of consolidation and application of the conventional theory.

Einstein (together with *Podolski* and *Rosen*: the '*EPR paradox*') questioned the completeness of quantum theory in 1935, suggesting that there were 'hidden variables' which would make the theory local and causal. Schrödinger took up this theme, coining the word '*entanglement*' to describe quantum states containing two or more objects. A resolution of the paradox however was not found until much later. *Von Neumann* had given a 'proof' that no hidden variables could exist, and it prevented further progress until the early 1950's. *David Bohm*, based on his study of the Copenhagen Interpretation, devised a new causal theory while working in São Paulo (at Tiomno's invitation): the '*de Broglie–Bohm theory*', which proposed a *guide field* for quantum objects, giving them a classical trajectory, while maintaining the Schrödinger equation for its time evolution. He also proposed a simpler 'test experiment' for the EPR paradox, using quantum spins as observables.

Bohm's ideas were considered in the early 1960's by *John Stewart Bell*, who in 1964–66 derived inequalities that must be obeyed by a hidden-variable theory. An experimentally-accessible version was proposed by *Clauser, Horne, Shimony* and *Holt* (1969) and tested in experiments performed by *Clauser* and by *Holt*, and by *Edward Fry*. A later, more definitive test was carried out by *Alain Aspect* in 1980–82, using an opto-acoustic switch to select entangled quantum objects (photons) before measuring their spins (polarizations), in a rigorous test of local causality (a similar experiment, the '*delayed-choice interferometer*', was proposed by *J.A. Wheeler* in 1978 and carried out by various experimenters in the 1980's). Thus, quantum mechanics has been found to be nonlocal and to contain no hidden variables. Many other experiments (in particular by the group of *Anton Zeilinger*, but also by several other groups) after 1998 have demonstrated the reality of 'quantum teleportation' and thus of entanglement and nonlocality. Due to applications in quantum computing and encryption, this field has become very active ('Quantum information').

Another unsolved difficulty in the Copenhagen Interpretation is the '*measurement problem*': What happens to a quantum system when one of its properties is fixed by a measurement? The quantum theory alone provides only the relative probabilities of particular outcomes of experiments over a spectrum of possible values. The search for a plausible description of the resulting '*wave-function collapse*' has led to a variety of interpretations, including variants of the '*many-worlds theory*' first suggested by Wheeler's student *Hugh Everett*.

Jayme Tiomno dealt with many aspects of fundamental quantum mechanics, staying however mostly in the realm of mathematical physics rather than the more speculative aspects of quantum interpretations.

***Suggested reading*:**

Tim James, '*Fundamental. How quantum and particle physics explain absolutely everything (except gravity)*'. Robinson, London (2019); ISBN 978-1-47214-347-1.

Louisa Gilder, '*The Age of Entanglement. When Quantum Physics was Reborn*', Alfred A. Knopf, New York (2008); ISBN: 978-1-4000-4417-7.

David Kaiser, '*How the Hippies Saved Physics*'. W.W. Norton & Co., New York (2011); ISBN 978-0-393-07636-3.

Cord Friebe *et al*., '*The Philosophy of Quantum Physics*'. Springer Nature, Cham CH (2018); ISBN 978-3-319-78354-3.

Jürgen Audretsch, '*Entangled Systems. New Directions in Quantum Physics*'. Wiley-VCH, Berlin (2007); ISBN 978-3-527-40684-5.

Abraham Pais, '*Niels Bohr's Times: In Physics,Philosophy, and Polity*'. Oxford University Press, New York (1991); ISBN 0-19-852049-2.

III. Tiomno's scientific work

On returning to São Paulo in October of 1950, Jayme Tiomno began working with great energy. The situation in the Physics Department at USP had deteriorated seriously since his departure in early 1948: Two important leaders, *Gleb Wataghin* and *Mario Schenberg*, had left. Schenberg had been active in the Communist party, and was arrested in 1948 when the party was (again) outlawed. He was able to travel to Europe some time later, and taught at the *Free University* in Brussels for several years before returning to USP in 1953. Wataghin had returned to Italy in September, 1949, and his chair at USP was still vacant. And *César Lattes*, who had returned from Berkeley in March, 1949, had moved on to Rio after only two months at USP, to take up his post as Scientific Director of the newly-founded CBPF and as professor at the FNFi, UB/Rio.

Tiomno worked with his colleague *Walter Schützer*, publishing two articles on the causal derivation of the S-matrix, later held to be an important foundation for that topic, which was actively pursued in the 1950's and 60's as an alternative to quantum field theories. He also collaborated with *David Bohm*, who arrived at USP in October, 1951 to take up Wataghin's vacant post (Bohm, also a some-time-member of the Communist party, had to leave the USA due to the cold-war repression of suspected communists). They published a joint paper on Bohm's causal quantum theory in 1955, the same year that Bohm left Brazil, settling finally in England (Bristol, then London) after an interlude in Israel. Tiomno however was eager to return to Rio, to the exciting project of establishing the CBPF, and to Elisa, whom he had informally married in early 1951.

Tiomno himself moved back to Rio in March, 1952, to take a position as professor at the CBPF and one of the leaders of its Theory Department, as well as an assistantship at the FNFi (a position not worthy of his education and experience, but which he needed in order to have access to students who might become research physicists at the CBPF). He and Elisa helped to establish the CBPF as an educational institution, recognized by the FNFi, where students could continue on to post-graduate work and become active in research.

Unfortunately, Tiomno had no time to write up and publish the results of his thesis, some of which were important for the development of weak-interactions theory. His thesis topic was '*Theories of the neutrino and double beta decay*'. He may have become interested in double beta decay by speaking to a fellow graduate student, *Edward Fireman*, who completed an experimental thesis on double beta decay in 1948, working with R. Sherr at Princeton. Or the topic may

Jayme Tiomno and Elisa Frota-Pessôa at the time of their informal marriage in Rio, early 1951.

have been suggested by Wigner, who had been interested in double beta decay since its original suggestion in 1935 by *Maria Goeppert-Meyer*. Tiomno had developed several theories of the neutrino and applied them to double beta decay, using the Fermi interaction with different current operators. His most important result was the ***chirality operator*** (which he called the '*mass-reversal operation*'), later important for theories of the weak interaction. He wrote a short paper relating the chirality operation to time reversal, which he however never published; it was circulated as a preprint in the *Notas de Física* of the CBPF in 1954. A year later, he wrote a paper for the *Nuovo Cimento* on '*Mass Reversal and the Universal Interaction*', which however did not consider parity non-conservation, still unexpected in 1955.

In 1956, T.D. Lee and C.N. Yang proposed that parity was violated in the weak interactions, and this was experimentally confirmed in early 1957. Lee and Yang were awarded the Nobel prize in 1957 for their theory. Tiomno submitted a revised theory of the weak interaction, taking parity non-conservation into account, to *Nuovo Cimento* in July 1957; but he used the wrong current operator combination, having forgotten Elisa's 1950 result on the positive pion decay, and thus missed the 'Universal V–A Theory', published later by Sudarshan and Marshak, and by Feynman and Gell-Mann, who received credit for the theory.

The period 1952–1960 has rightly been called the '*Golden Age*' of the CBPF. It became established as an important center for physics research, in Latin America and in the entire world, and attracted many talented scholars and students. In spite of political controversies and funding problems, it was able to maintain that position throughout the 1950's.

Tiomno's work, particularly in particle physics (*weak interactions*: introduction of the *Universal Fermi Interaction and,* in his thesis, the *chirality operator*, important for the V–A theory; *strong interactions* (hadron physics), especially the prediction of the *K' meson* in 1959–60), and in establishing research groups and graduate education, made an important contribution to the reputation of the CBPF, which benefited from its democratic structure during this period.

Tiomno also made numerous trips abroad, beginning in 1954, and established collaborations with physicists in several countries (*see Part V*). In 1958–59, he and Elisa spent a year as guest researchers in London (JT at the Imperial College, where his collaborator and friend *Abdus Salam* was now head of the Theoretical Physics department; Elisa at the University College, working with *Eric Burhop* and the K^- collaboration).

Tiomno and Elisa in Paris, June 1959, at the end of their London stay. Tiomno was attending the *Conference on Relativistic Theories of Gravitation* at nearby Royaumont, the third in the GR Conference series which began in Bern in 1955.

After their return to Rio and the CBPF in mid-1959, Jayme Tiomno and Elisa Frota-Pessôa experienced a difficult period in their lives and careers. A fire had destroyed the CBPF's library and Elisa's laboratory in early 1959. Elisa's health was poor for the next 5 years, limiting her work and participation in their joint projects. The political and economic situation, both at the CBPF and in Brazil as a whole, was unstable and worsened over the next years, culminating in the military *coup d'état* at the end of March, 1964. This was followed by a military dictatorship, increasingly authoritarian and repressive. These tendencies were intensified by leaders at the FNFi and the CBPF, even before the military regime took power.

Tiomno also participated in founding several institutions during the 1960's (ICTP, 1962–64; Physics Institute, UnB, 1962–66; Mathematical Physics at USP, 1968–69. *See Part IV*). His scientific productivity declined accordingly, and he published only 16 papers in that decade, in contrast to 26 in the 1950's and 21/37 in the 1970's/80's. His scientific publications in the 1960's were concerned mainly with hadron physics (K' meson, hyperons, global symmetry).

A.L.L. Videira, ***J. Tiomno***, and ***N. Zagury***, announcing their paper in *Physical Review Letters*, predicting the K' meson, at the *Academia Brasileira de Ciéncias* (ABC), May 1961.

The decade of the 1960's also marked the catastrophic failure of the UnB in Brasília in 1965. Thereafter, Tiomno spent a year at the newly-founded ICTP in Trieste (1966/67), where he began a fruitful collaboration with C.G. Bollini and J.J. Giambiagi that continued for over 15 years. Following his new start at USP in 1968. Tiomno was blacklisted by the military regime and forced to retire in May, 1969, An especially important paper published about this time was '*A Linear Theory of Gravitation*', with Bollini and Giambiagi (BGT collaboration), *Nuovo Cimento **3***, 65 (1970), prepared while he was still at the ICTP.

Left: Armed troops occupying the *Universidade de Brasília* (UnB) in October, 1965. This provoked the end of the ambitious project of the UnB, for the time being.

Right: Juan José Giambiagi, Jayme Tiomno, and Carlos Guido Bollini at the International Centre for Theoretical Physics (ICTP) in Trieste, 1966.

Tiomno and Elisa returned from Trieste to USP in mid-1967; Jayme Tiomno had entered a *concurso* for the Chair in Advanced Physics there (previously occupied by César Lattes on a temporary basis) and won, taking up his new position in early 1968. He was able to work productively for just over a year there, setting up the group which became the nucleus of the Department of Mathematical Physics a few years later. His own research took a low priority relative to his administrative and scientific leadership roles, however, especially due to the impending university reform and various disputes within the department. In May, 1969, he was forcibly retired as a professor by the military regime, which considered him to be 'subversive', along with many others. His planned return to the CBPF, a private foundation, was blocked by its president, who supported the regime. So Tiomno, as well as Elisa, and Leite Lopes, founders of the CBPF, were no longer permitted to work there. After a difficult year, in which he traveled, looking for alternatives, Tiomno accepted an invitation to the IAS in Princeton, and went there with Elisa in early 1971.

Wheeler had in the meantime shifted his work to gravitation, field theory, relativistic astrophysics and cosmology, leaving particle physics behind in 1952 /53, and had established a large and successful research school at Princeton, which Tiomno joined. He took up topics in which he had been interested since student days, but had not pursued, with some exceptions; and he published over a dozen papers in the new field, with *Remo Ruffini* and *Leonard Parker*, senior researchers in Wheeler's school, and with several other, younger theoreticians as well as working alone (*see Part V*).

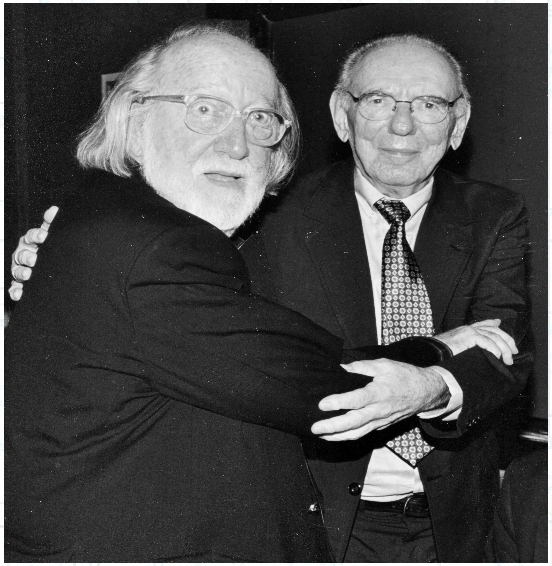
Tiomno and Elisa returned to Brazil in June, 1972. Their situation there had not improved, and only after long negotiations (and a papal intervention) was he able to find a position at the Catholic University in Rio (PUC/RJ), although even there, he was not allowed to serve as a mentor for students' research. He nevertheless established a research group, and Elisa was able to set up a laboratory with help from USP. After several years, Tiomno began publishing again, and completed a series of papers with Bollini and Giambiagi (they were now at the CBPF, having escaped from the even more stringent dictatorship in their native Argentina), on aspects of gauge theories and on Wilson loops.

Finally, as the dictatorial controls were loosened in the late 1970's and early 80's, an amnesty was proclaimed, and Tiomno was able to return to the newly reorganized CBPF in 1980. The following decade was his most productive, with 37 publications in an astonishing breadth of fields: Relativity (Special and General), astrophysics and cosmology, hadronic physics, mathematical physics as well as the history and sociology of physics and physics education.

Tiomno officially retired from the CBPF in 1990, when he turned 70. But for him and some other members of the founders' generation, a special title, *pesquisador emérito*, was created by the CBPF and conferred on Tiomno, Elisa Frota-Pessôa, José Leite Lopes, Leopoldo Nachbin, Hervásio Guimarães de Carvalho and Francisco Mendes de Oliveira in August, 1992. Tiomno continued to be active in research planning and administration, and on several projects of his own, in particular rotating relativistic systems. He received many honors late in his life and was a public figure until shortly before his death in January, 2011 (precisely 60 years from the date of his informal marriage to Elisa).

Above, left: Tiomno and Elisa with their former student and collaborator, *Mario Novello*. In 1991. ***Right***: John Wheeler and Elisa Frota-Pessôa in Princeton, 1993.

Below left: Jayme Tiomno's last collaborator, *Ivano Soares*, with Tiomno in 1997.
Below right: José Leite Lopes and Jayme Tiomno, accepting the institutional *Marcel Grossmann Prize* for the CBPF at MG-X in Rio de Janeiro, 2003. This conference series on Relativistic Astrophysics was founded by Remo Ruffini and Abdus Salam in 1975.



Suggested reading:

William Dean Brewer and Alfredo Tiomno Tolmasquim, *'Jayme Tiomno – A Life for Science, a Life for Brazil'*, Springer/Nature, Cham CH (2020); ISBN 978-3-030-41010-0 (JT2020).

José Leite Lopes, '*Uma História da Física no Brasil*', Livraria da Física, São Paulo (2004); ISBN 978-858-832519-7.

Jayme Tiomno, '*Memorial Relativo às Atividades Profissionais de Jayme Tiomno*' (1966), Tiomno Archive, MAST, Rio de Janeiro ([JT]). *See also* Jayme Tiomno, list of his own '*Papers of Major Importance*', (1995); [JT], *and* Jayme Tiomno, '*A física de partículas: o início dos trabalhos de física de partículas no Brasil*' (2005); [JT].

S.W. MacDowell, H.M. Nussenzveig, and R.A. Salmeron, eds., '*Frontier Physics — Essays in Honour of Jayme Tiomno*', World Scientific, Singapore (1991); ISBN 978-98-145-3907-4.

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José Maria Filardo Bassalo, '*Jayme Tiomno, os Mésons e a Física Paraense*', CBPF: *Ciência e Sociedade*, Document CBPF-CS-005/87 (1987).

José Maria Filardo Bassalo, '*O Instituto Central de Física Pura e Aplícada da Universidade de Brasília, em 1965*'. CBPF: *Ciência e Sociedade*, Document CBPF-CS-010/12 (June 2012).

Laurie Mark Brown, Max Dresden, and Lillian Hoddeson, eds., '*From Pions to Quarks. Physics in the 1950's*'; based on a Fermilab Symposium, May 1985. Cambridge University Press, Cambridge/UK, New York/USA (1989); ISBN 0-521-30984-0.

IV. Physics Institutions: CBPF, ICTP, UnB, USP, SBF...

Tiomno was interested in establishing institutions to support and improve scientific education and research during most of his life. That interest probably arose during his own early education, when he was denied the chance to study at the UDF and given little supervision in his early research at the FNFi. Along with *José Leite Lopes* and *Elisa Frota-Pessôa*, and later joined by *César Lattes*, Tiomno was an early supporter of the *Centro Brasileiro de Pesquisas Físicas* (CBPF) in Rio, and helped to plan it and to develop it throughout his professional life (when he was allowed to).

Although he was in Princeton when the CBPF was 'officially' founded in January, 1949, Tiomno had contributed actively to its planning and realization. He joined it as a full member in March, 1952, and organized its Teaching Department as well as founding the preprint library *Notas de Física* soon afterwards. Later, he founded its Graduate School and obtained funding for it through UNICEF. After returning to the 'new' CBPF in 1980, he was initially its Scientific Director. He helped to found the *Department of Relativity and Particles* (DRP), and later the *LAFEX Department*, which supports participation of CBPF members in international experimental high-energy physics projects.

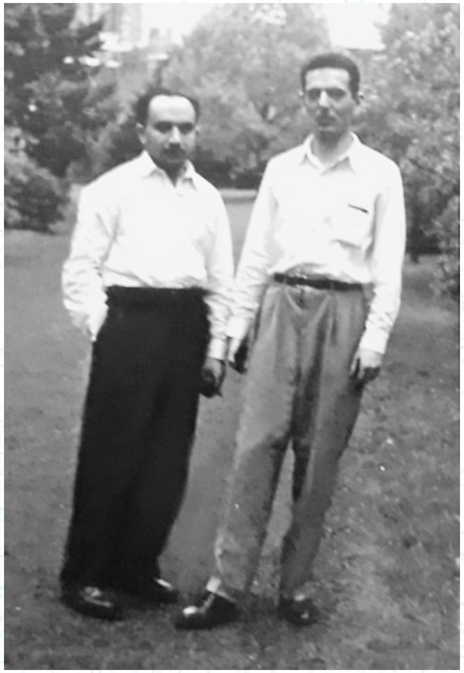
The CBPF with 'science graffiti', 2019

In the early 1960's, Tiomno was an important contributor to two other institutional projects: (i) Founding the *International Centre for Theoretical Physics* (ICTP) in Trieste, Italy, proposed and supported by his friend and collaborator (and later Nobel prizewinner) *Abdus Salam*. Tiomno was a member of the '*Three Wise Men*' committee which planned the ICTP in 1962/63. After the Centre began operations in 1964, he was its Associate and often spent time there. In 1995, he was awarded the Physics Prize of the associated *Third World Academy of Sciences* (TWAS).

(ii) And from 1960, he was a member of the *Planning Commission* for the new Physics Institute at the *Universidade de Brasília* (UnB), an ambitious project backed by *Anisio Teixeira* and *Darcy Ribeiro*. Tiomno's colleague and friend *Roberto Salmeron* came from CERN (Geneva) to set up the Institute, and in 1965, Tiomno and Elisa went with a number of their students to begin teaching and research there. Interference by the military regime and poor management by the Rector led to the invasion of the campus and the mass retirement of most of the faculty in October, 1965.

Left: The ICTP Campus in Trieste, 2018.

Right: The Central Institutes building at the UnB Brasília, 2016.

Image, left: Jayme Tiomno and Abdus Salam, early 1960's. ***Right***: Darcy Ribeiro speaking at the founding ceremony of the UnB, 1962.

Following the collapse of the UnB project, Jayme Tiomno and Elisa Frota-Pessôa went to São Paulo, where he obtained the professorship in Advanced Physics at USP, and began his teaching and research duties there in early 1968. He established a group in Theoretical Physics, which grew rapidly and was the largest and most successful in the country by early 1969. After Tiomno's forced retirement in May, 1969, his group became the nucleus of the *Department of Mathematical Physics* at USP, which later recognized him as its founder by naming a lecture room after him. In Tiomno's absence, his group was led by visiting professors from abroad. The first of those was ***Enrico Predazzi***, from Turin, Italy. He was later an important collaborator with Tiomno.

The *Sociedade Brasileira de Física* (SBF) was founded in July, 1966 in *Blumenau*, S.C. at a meeting of the SBPC there. Jayme Tiomno was one of its founders and served as its first Vice-President. He was later recognized in several special sessions at meetings of the SBF. He was likewise an early supporter of the state science funding agency FAPERJ in Rio de Janeiro state, and received its medal '*Carlos Chagas Filho do Mérito Científico*' at the 25th anniversary ceremony in the *Theatro Municipal*, RJ in December 2005.

Jacob Palis (à esq.) e Jayme Tiomno, um dos homengeados pela FAPERJ

Above, left: Jacob Palis (President of the ABC) and Jayme Tiomno at the 25th anniversary celebration of FAPERJ in Dec. 2005, where Tiomno received an award.

Center: Tiomno speaking after receiving the *Premio Moinho Santista* in 1957.

Right: The cover of the anniversary report of the SBF, 50 years after its founding. This report contains a chapter on the physicists who were blacklisted by the military regime after 1968.

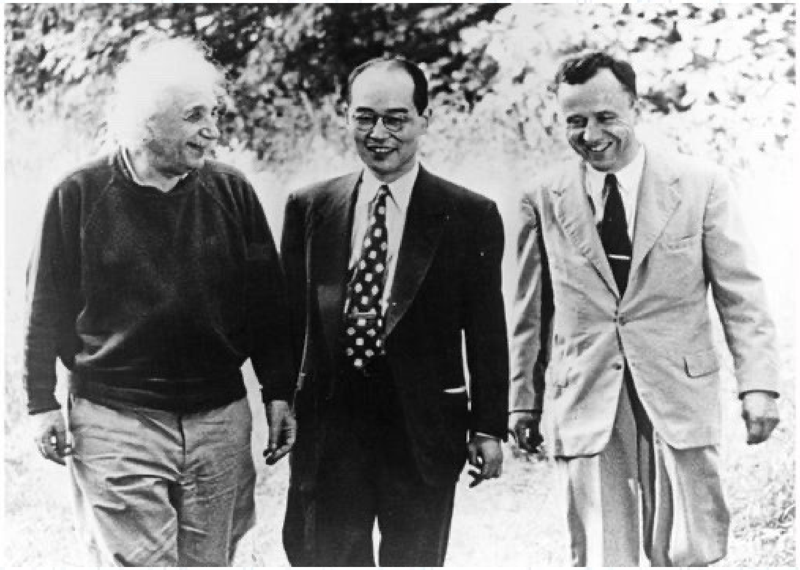
V. Collaborative physics: Work with many partners.

Tiomno was well known for his cooperative attitude and readiness to collaborate, both with senior physicists and with younger students and post-docs. This attribute was praised in the *laudatio* when he received the *Premio Moinho Santista*, a prestigious and rewarding science prize, as the first physicist to be awarded the prize in 1957. His collaboration partners included many internationally-renowned scientists, and by the early 1960's, he was part of a large network of talented theoretical physicists all over the world, in spite of being 'isolated' in Brazil, at that time just developing its own physics community. Here, we mention some of his more important collaborators.

Tiomno's first collaborator and lifelong friend was *José Leite Lopes*. Discovered in Pernambuco by *Luis Freire* in 1939, Leite Lopes went to Rio to study at the UDF, where Freire was Rector at the time, but had to transfer to the FNFi/UB when the UDF was closed by the Vargas regime. He later received his doctorate at Princeton, the first Brazilian physicist to do so. He and Tiomno collaborated on theoretical particle physics in the late 1940's, and later on a number of educational and administrative projects, including the founding of the CBPF.

José Leite Lopes, laughing at a joke made by *Wolfgang Pauli*, one of his PhD advisors; probably early 1950's.

When Tiomno went to Princeton in early 1948, he joined the group of *John A. Wheeler*, 9 years older and already a well-known theoretician in particle physics. Wheeler is known for having worked in all three of the major themes of 20th-century physics, which he called '*Everything is Particles*', '*Everything is Fields*', and '*Everything is Information*'. When Tiomno joined his group, he was nearing the end of the first theme, but he gave Tiomno a project in General Relativity to work on – perhaps a sign of his impending change to Field Theory and Gravitation. Wheeler and Tiomno had a brief, intense collaboration on meson theory and Weak Interactions (at the time called the 'Universal Fermi Interaction' (UFI), a name coined by Tiomno and C.N. Yang), publishing 5 papers in 1948/49, and Wheeler remained a lifelong supporter of Tiomno, inviting him back to Princeton after he was blacklisted in Brazil in 1969, and even nominating him for a Nobel prize in 1987. Tiomno himself also worked in all three of those major topics, in part inspired by Wheeler, but always maintaining his own originality and independence.



Albert Einstein, ***Hideki Yukawa*** and ***John Archibald Wheeler*** in Princeton, 1953. Wheeler had by that time recently changed his area of interest from particle physics to gravitation and field theory.

Tiomno had three other important collaborators while at Princeton: *Eugene Wigner*, who became his PhD advisor after Wheeler left on sabbatical in June, 1949; *Chen Ning Yang*, who had received his PhD under Teller and Fermi at Chicago and joined the Institute for Advanced Studies (IAS, ironically called the '*Princetitute*' by Bohm; at that time directed by J.R. Oppenheimer) in 1949. He and Tiomno published an (historically) important paper in early 1950, using the term 'UFI' for the first time. They were lifelong friends and collaborated briefly on other topics in particle physics in the years 1950–70. His third collaborator at Princeton was *David Bohm*, three years older than Tiomno, who was Assistant Professor at Princeton University from 1947–51. They started a project on the Dirac equation in General Relativity, which Tiomno continued a dozen years later. Tiomno was later instrumental in inviting Bohm to São Paulo, where he occupied the Chair established for Gleb Wataghin from 1951–55. There, Tiomno published a joint paper on Bohm's deterministic quantum theory with him (1955).

Left : ***Eugene Wigner***, about 1950. ***Center***: ***Chen Ning Yang***, 1956. Wigner and Yang were both later Nobel prize winners.

Right: ***David Bohm***, reading about his impending arrest, in 1950.

After returning to Brazil in October, 1950, Tiomno collaborated with his fellow student *Walter Schützer*, who had also obtained his MSc at Princeton. He in addition worked with *David Bohm* after the latter arrived at USP in October, 1951. After moving to the CBPF in March, 1952, Tiomno worked with a number of students and younger scientists, but also collaborated with *J.J. Giambiagi* from Argentina, who was working at the CBPF to avoid a political purge at his home university (the UBA in Buenos Aires).

In 1956, Tiomno met *Abdus Salam*, a young Pakistani physicist then working in England. They became friends, no doubt due to their mutual interest in neutrino physics and in promoting physics in the 'third world'. Their collaboration continued for a number of years, at first in science (mainly the weak interaction; Abdus Salam received the Nobel prize in 1979, together with Sheldon Glashow and Steven Weinberg, for their work on the electroweak unification), and later in establishing educational and research institutions. Tiomno visited the Imperial College in London for a year in 1958/59, where Abdus Salam had recently become head of the Theoretical Physics Department, and they continued their collaboration there and afterwards.

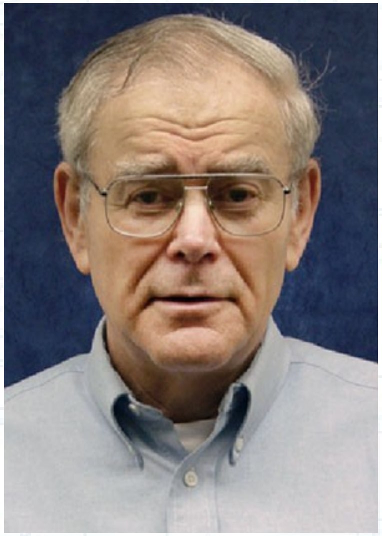
Abdus Salam, 1950's.

Tiomno's most important work in the early 1960's was his prediction of the K' meson, published together with two younger colleagues, *A. Luciano L. Videira* and *Nicim Zagury*, and soon verified by the Berkeley group (*Luis Alvarez et al*.). After the attempted founding of the Physics Institute at the UnB in 1965, where he worked with *Elisa Frota-Pessôa* and *Roberto A. Salmeron*, Tiomno spent a year at the ICTP in Trieste, where he began a long collaboration with the two Argentine physicists *J.J. Giambiagi* and *C.G. Bollini*. Those two had met at the Argentine Atomic Energy Agency (CNEA) after Giambiagi returned to Argentina in 1956, and Tiomno met Bollini later, in 1958 when both were working in London. This collaboration (BGT) published around 10 joint articles between 1966 and 1982, including their '*Linear Theory of Gravitation*', an alternative to Einsteinian gravitational theory, in 1970. Their collaboration was resumed in the later 1970's while Tiomno was working at PUC/RJ and they were at the CBPF.

Left: Juan José Giambiagi, ca. 1958, and ***right***: Carlos Guido Bollini, early 1960's

While at Princeton in 1971–72, Tiomno collaborated with *Remo Ruffini* and with *Leonard Parker*, as well as with a series of younger colleagues who were students or postdoctoral assistants there or nearby. See JT2020 for details. Tiomno published about a dozen papers in 1971–75 from those collaborations (or alone, but stimulated by the collaborations at Princeton).

After returning to the CBPF in 1980, Tiomno again collaborated with a number of younger researchers, some of them his former students. Particularly important among his more senior collaborators was *Enrico Predazzi* from Turin (works on hadronic physics, especially 'charmed' particles), and his earlier student *Mario Novello*, with his own doctoral student, *Ívano Soares.*



Left : ***José Leite Lopes***, ***Jayme Tiomno***, and ***Remo Ruffini***, at the 10th *Marcel Grossmann Meeting* on relativistic astrophysics, in Rio de Janeiro, 2003.
Center: ***Leonard Parker***, at the University of Wisconsin, around 2015.
Right: ***Enrico Predazzi***, Turin, around 2015.

At the CBPF in the 1980's, Tiomno worked on a wide variety of projects, and had many other collaborators, mostly younger physicists. A complete list is to be found in JT2020. After his official retirement in the early 1990's, he worked on finding a relativistically-correct description of rotating systems (Sagnac effect, Mashhoon effect), collaborating mainly with *Ívano Soares*. His last scientific paper was given in 2007 on this topic at a meeting of the SBF.

Suggested reading:

F. David Peat, '*Infinite Potential: The Life and Times of David Bohm*', Addison Wesley, Reading/MA (1997); ISBN 0-201-32820-8.

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Chen Ning Yang, '*Selected Papers, 1945-1950, with commentary* ', World Scientific Publishing Co., Singapore (2005); ISBN 981-256-367-9.

Carolina Cronemberger, ed., *Algumas razões para ser uma cientista.* CBPF, Rio de Janeiro (2005). Interview with Jayme Tiomno, '*Trabalho Duro*', p. 96. Available online as a pdf.

Conclusions

The three major strands of fundamental physics in the 20th century have wound their way through the decades, producing many offshoots and sometimes seeming to fuse into a single strand. They each experienced periods of hectic activity and rapid progress, and longer periods of relative neglect and apparent stagnation.

Particle physics reached its preliminary climax in the late 1970's with the formulation of the Standard Model of Particle Physics (SMPP), combining the electroweak unified theory with quantum chromodynamics to describe three of the four fundamental interactions (weak, strong, electromagnetic); however leaving gravity out of the picture. In the intervening 40 years, the SMPP has been completed and perfected, but – although no-one really believes it to be the 'last word' on the microscopic world – the predicted 'new physics' beyond the SMPP has failed to appear, both experimentally and theoretically.

Gravitational physics has also produced the Standard Model of Cosmology (SMC), based on GR, and it has been enriched by many new discoveries and technical advances. But the SMC leaves many open questions and unsolved problems – dark matter, dark energy, inflation; and its fundamental constant, the *Hubble constant*, is presently the subject of conflicting measured values.

Fundamental quantum mechanics has given rise to a number of important offshoots – quantum optics, quantum information, quantum computing – but the 'correct' interpretation of quantum mechanics is still elusive, as is its combination with gravity – *quantum gravity*.

Jayme Tiomno contributed significantly to all three of those major strands. But also, and for him more importantly, he contributed to the establishment and improvement of physics education and research in his native country, Brazil. This was his most serious goal during his long lifetime, and he made major contributions to its present success. The lesson to be learned from his lifelong efforts is that serious and honest work often leads to unexpected and lasting successes, even though it faces drastic obstacles and may appear hopeless for the time being. As Tiomno himself said near the end of his life, *"tínhamos a convicção de que íamos chegar lá".*

Left: A lunch offered by the CBPF, around April, 1952 at the *Sol e Mar* restaurant in Botafogo, Rio. A list of the participants can be found at https://digital.archives.caltech.edu/islandora/object/image%3A1871

Right, standing: Roberto Frota Pessôa, Suely Braga da Silva, Silvia Tiomno Tolmasquim; ***seated***: Sonia Frota Pessôa, William D. Brewer. Rio, February 1999.