“ Dirac,
Emancipador e Transgressor ”

CBPF

(Ospedal – Helayël)

MAR 2019

Importante esclarecer a apresentação

- **Que Dirac pretendo apresentar**

  [Dirac, emancipador? Dirac, transgressor?]

- **A partir de quais referenciais**

- **Com que propósitos**

  [*Dirac nos traz lições em muitas frentes.* **]**

A mágica noite de 12 de Agosto de 1982 em Erice

- **Zichichi e Salam organizaram a inesquecível noite "My Life as a Physicist":**

- **Wigner**
- **Dirac**
- **Yang (Festa dos 60 anos; 1º OUT 1922).**

Paul Adrien Maurice Dirac em 3 notas:

- **impressionante intuição física**
- **incomparável capacidade de criar nova Matemática para gerar nova Φ (o Dirac filosófico)**
- **e, importante: um claro posicionamento político, com importante consequência para a Φ.**

Dirac e os 3 anos decisivos para a elaboração do Modelo-Padrão

- **1925 – 1926**

  Dirac lança as bases da **Mecânica Quântica**

- **1926 – 1927**

  As bases da **Teoria Quântica de Campos**

- **1927 – 1928**

  As bases da **Física de Partículas Elementares**

Os alicerces do

Modelo-Padrão da Física de Partículas.

O 1º momento com a Mecânica Quântica

- **Dirac chega a Cambridge em 1923 ~ Ralph Fowler**

- **AGO 1925: Fowler recebeu as "proof-sheets" do trabalho ainda não publicado de Heisenberg - o 1º esboço da MQ – e o passa imediatamente a Dirac, que mergulha no material, repropondo a Mecânica Matricial de Heisenberg em termos dos chamados q-numbers.**

- **NOV 1925, "The fundam'l eq'ns of QM", PRS 109 (NOV'25) 642.**
- **MAI 1926, PhD Thesis, "Quantum Mechanics".**
- **AGO 1926, "On the theory of QM", PRS 112 (AGO'26) 661.**
- **DEZ 1926, "The physical interpretation of the quantum dynamics", PRS 113 (DEZ'1926) 621.**

A Relação Φ – M:
peça fundamental para compreender Dirac na Φ

- **Bacon**:

"For the things of this world cannot be made known without a knowledge of Mathematics."

- **Russel**:

"Mathematics, rightly viewed, possesses not only truth, but supreme beauty."

- **Dirac**:

"**Beauty is the method**."

The Relation between Mathematics and Physics
PRS (Edinburgh) 59 (1938-1939), Part II, p.122.

A Relação Φ - M

- *"Mathematics is a part of Physics. Physics is an experimental science, a part of natural science.*
  Mathematics is the part of Physics where experiments are cheap."
  V. I. Arnold, matemático russo (1937 – 2010).

- *"The physicist, in his study of natural phenomena, has two methods of making progress: (1) the method of experiment and observation, and (2) the method of mathematical reasoning. The former is just the collection of selected data; the latter enables one to infer results about experiments that have not been performed."*
  P. A. M. Dirac (1902 – 1984).

- **Φ – M: nova Matemática para trabalhar os nossos problemas, e não criar novos problemas para a Matemática tradicional.**

Crítica Genética

- **L. Hay**, 1979: « **Les Essais de critique génétique** ».

- Inicia-se como acompanhamento crítico do processo de criação na Literatura.

- Na década de ‘90, estende-se para demais áreas: abordagem para a obra a partir da consulta e análise de documentação referente [*documentos de processo*] ao trabalho de criação:

  diários, esboços, anotações, correspondências, marginálias, entrevistas, roteiros, contatos.

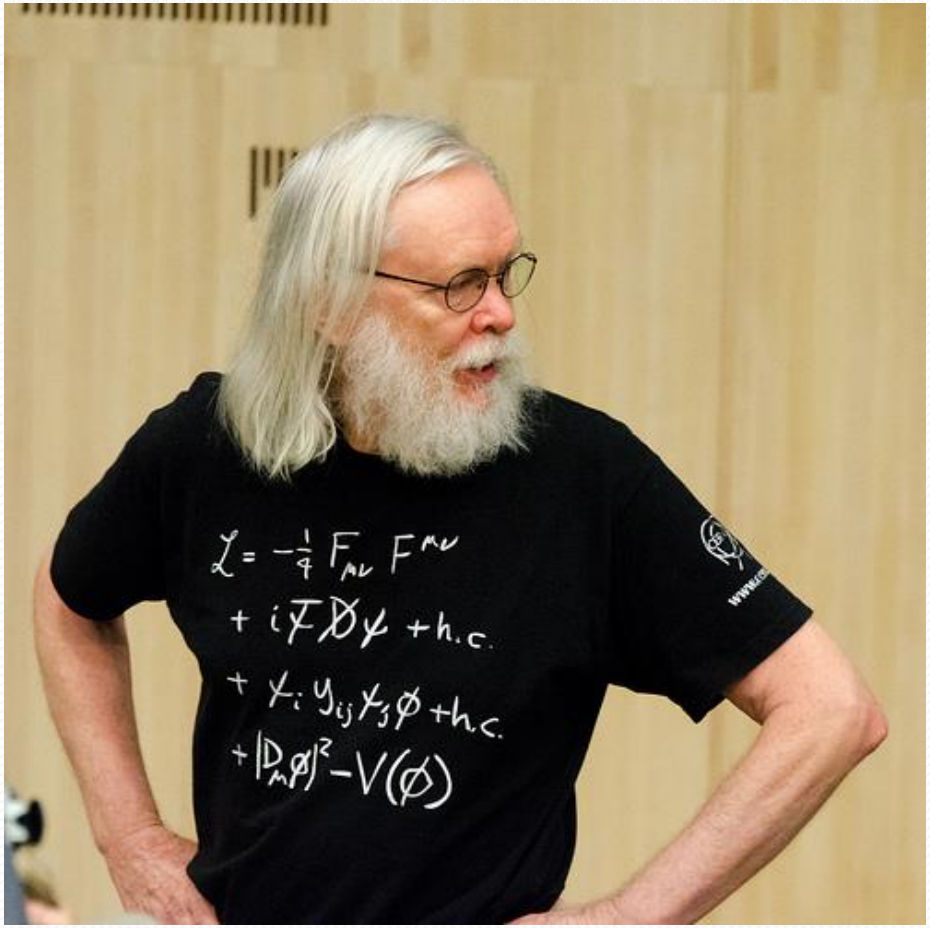
Crítica Genética

- O que está em questão não é a obra em si, mas sim **o processo de construção da obra**; **as grandes questões no contexto deste processo**.

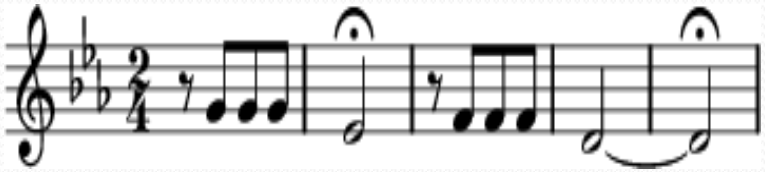
- Busca-se detectar e compreender os procedimentos que possibilitam a concepção.

- E. Morin (“A inteligência da complexidade”, pág. 23): ***“Arte de transformar detalhes aparentemente insignificantes em indícios que permitam reconstruir toda uma história.”***

Dirac, a Gênese do Modelo-Padrão



Dirac/Beethoven, Simplicidade e Eternidade



Dirac/Einstein, Simplicidade e Estética

$$(i\,\Gamma^{\mu}\,\partial_{\mu} - m)\,\psi = 0$$

$$R_{\mu\nu} - \tfrac{1}{2}\, g_{\mu\nu}\, R = 0$$

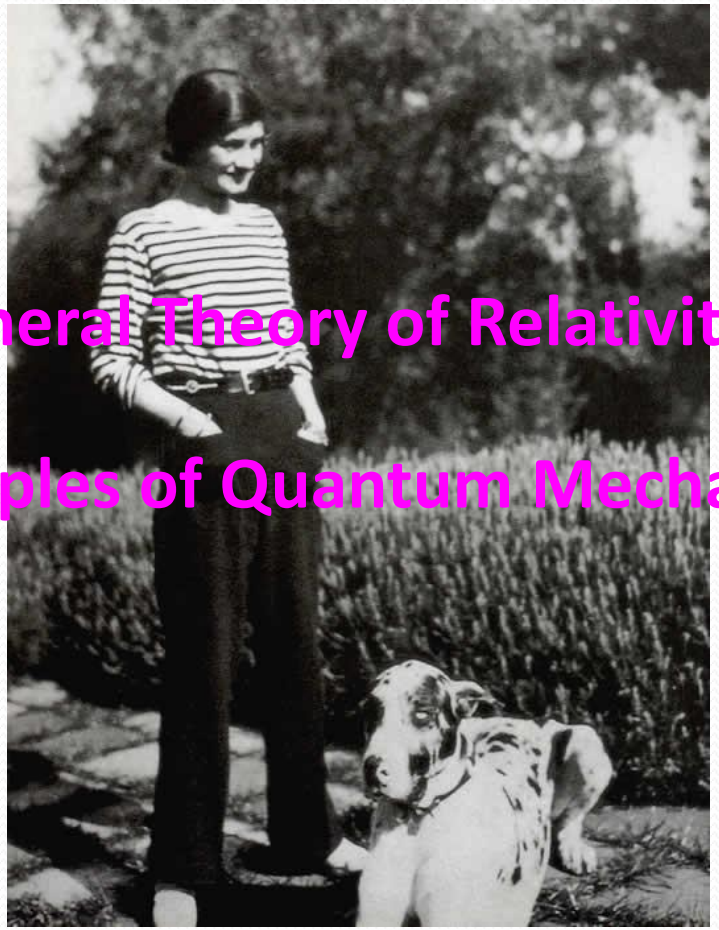
Dirac/Stein, Simplicidade e Poesia

Rose is a rose is a rose is a rose
Loveliness extreme.
Extra gaiters,
Loveliness extreme.
Sweetest ice-cream.
Pages ages, page ages, page ages.

(**Gertrude Stein**, **“Sacred Emily”**, in *Geography and Plays*)

Simplicidade e Estilo: Dirac, um estilista da Φ?

Dirac buscou a beleza e a estética pela simplicidade



"General Theory of Relativity", 1975

"The Principles of Quantum Mechanics", 1930

“A Beleza é o Método”

- ***“What makes the theory of relativity so acceptable to physicists in spite of its going against the principle of simplicity is its great mathematical beauty. This is a quality which cannot be defined, any more than beauty in art can be defined, but which people who study mathematics usually have no difficulty in appreciating. The theory of relativity introduced mathematical beauty to an unprecedented extent into the description of Nature.”*** **(Dirac, 1939).**

- **A Matemática como legítimo instrumento de investigação da Natureza: superação dos limites da tecnologia de uma época.**

- **A simplicidade e a estética como critérios formais para a construção de uma teoria.**

- **O estruturalismo de Dirac através da obra de Bakhtin**
  (crença e busca contínua pela elementaridade).

A Tensão Pré-Diraqueana

- **Cartan (série de aulas), 1913: Teoria dos Espinores**
- **Einstein, 1917: Considerações cosmológicas na RG (Introdução da constante cosmológica; mas a origem?)**
- **Rutherford, 1919: descoberta do próton**
- **Compton, 1923: o fóton como uma nova partícula**
- **Goudsmit – Uhlenbeck, 1925: spin do elétron**
- **Heisenberg, 1925: Mecânica Matricial.**

O momento da transição - da era pré-Dirac à era Dirac

- **Heisenberg, DEZ 1925: Matrix Mechanics**
- **Dirac, MAY 1926, PhD Thesis: "Quantum Mechanics"**
- **Schrödinger, DEZ 1926: equação de onda**
- **Dirac, FEV 1927: campos quantizados (QED)**
- **Pauli, MAI 1927: Equação de Pauli (*spin não-relativístico*)**

A Alvorada da QFT

- **Dirac, 1927**

"The quantum theory of absorption and emission of radiation"
PRSL **A114** (1927) 243;

"The quantum theory of dispersion", PRSL **A114** (1927) 710.

- **Pauli and Jordan, 1928**

"On the Quantum Electrodynamics of Free Fields", Z. Phys. **47** (1928) 151.

- **Fermi, 1929**

"Sopra l'Elettrodinamica Quantistica", Rend. Accad. Lincei **9** (1929) 881.

- **Pauli and Weisskopf**, 1934 (**the famous anti-Dirac paper**)

"On the quantisation of the relativistic wave equation for scalars",
Helvetica Physica Acta **7** (1934) 709.

O clímax para a Equação de Dirac

3 partículas elementares: e, p, γ – Nasce o Modelo-Padrão

- **Dirac, 1928 – 1931: lançando as bases do Modelo-Padrão**

"The quantum theory of the electron - I" (2 JAN 1928) [*o problema de Pauli !* **]**
"The quantum theory of the electron - II" (2 FEV 1928)

"A theory of electrons and protons" (6 DEZ 1929): 90 anos do Vácuo Quântico
vácuo quântico x constante cosmológica *(retornando a Einstein 1917!)*

Elementaridade ? "The Proton" (18 OUT 1930) – prévia das anti-partículas

Elementaridade ? "Quantised singularities in the e.m. field" (29 MAI '31)
pelos resultados deste trabalho recebe o Nobel de 1933:
"for the discovery of new productive forms of atomic theory"

- **Weyl, 1929: "Elektron und Gravitation - I" (8 MAI 1929) [Dirac, presente!]**
(equação de Weyl para férmions de massa nula)

[Dirac, presente!] A carta de Pauli e a proposta dos NUs

Physics Institute Zürich
of the ETH Gloriastrasse
Zürich

December 4, 1930

Dear Radioactive Ladies and Gentlemen,

As the bearer of these lines, to whom I graciously ask you to listen, will explain to you in more detail, because of the "wrong" statistics of the N- and Li-6 nuclei and the continuous beta spectrum, I have hit upon a desperate remedy to save the "exchange theorem" (1) of statistics and the law of conservation of energy. Namely,

the possibility that in the nuclei there could exist electrically neutral particles, which I will call ***neutrons****, that have* ***spin-1/2*** *and obey the exclusion principle and that further* ***differ from light quanta*** *in that they do not travel with the velocity of light. The mass of the neutrons should be of the same order of magnitude as the electron mass and in any event* ***not larger than 0.01 proton mass***.

The continuous beta spectrum would then make sense with the assumption that in beta decay, in addition to the electron, a neutron is emitted such that the sum of the energies of neutron and electron is constant.

... Finalizando a carta de Pauli

... I admit that my remedy may seem almost improbable because one probably would have seen those neutrons, if they exist, for a long time.

But nothing ventured, nothing gained, and the seriousness of the situation, due to the continuous structure of the beta spectrum, is illuminated by a remark of my honored predecessor, Mr. Debye, who told me recently in Bruxelles:

"Oh, It's better not to think about this at all, like new taxes."

Therefore one should seriously discuss every way of rescue. Thus, dear radioactive people, scrutinize and judge. Unfortunately, I cannot personally appear in Tübingen since I am indispensable here in Zürich because of a ball on the night from December 6 to 7. With my best regards to you, and also to Mr. Back, your humble servant

- Signed W. Pauli.

- *[Translation: **Kurt Riesselmann**.]*

[Dirac, presente!] Fermi - 1933

- **“Tentativo di una teoria dei raggi-β”**
  La Ricerca Scientifica 2, fasc. 12, 1933.

- Adota a formulação da QED proposta por Dirac em ’27, seu próprio (Fermi) paper de 1929 e elabora interação 4-férmions.

- **Revê o limite de massa do NU proposto por Pauli.**

- **Estima a constante de acoplamento fraca, G_F .**

Dirac, a ex-União Soviética e o Japão

- **1935**, o celebrado paper de **Yukawa** [**Dirac, presente!**]

  "**On the interactions of elementary particles**",

  Prog. Theor. Phys. **17** (1935) 48.

Os trabalhos precedentes de Dirac são fundamentais para **Igor Tamm (Nobel 1958)** (o amigo extrovertido, tal como a **Sra. Margit**) propor o seu trabalho sobre as forças nucleares:

"**Exchange forces between neutrons and protons and Fermi's theory**"

Nature 133 (1934) 981, [**Dirac, presente!**],

que foi crucial para o trabalho acima de Yukawa.

[Tamm foi o Referee do paper-I da Equação de Dirac.]

Viagens à URSS e Japão: 1929, '30, '32, '33, '35, '36, '37, '38, '56, '65, '73.

[Dirac, presente!] O Vácuo de Dirac e Efeitos não-lineares na ED

- **1933 - O. Halpern**
  [Vácuo de Dirac e não-linearidades na ED]
- **1933 – Espalhamento de Delbrück**
  [Meitner – Kösters; *comments by Delbrück*]
- **1934 – Born e Born-Infeld**
- **1935 - H. Euler e B. Köckel [Luz – Luz]**
- **1936 – Euler e Euler-Heisenberg**
  [Polarização do vácuo e ED não-linear a partir do vácuo quântico]
- ***Hoje, 15 extensões não-lineares na literatura.***

Integral de caminho, polarização do vácuo e renormalização da carga na QED

- **Dirac, 1933:**

"The Lagrangian in Quantum Mechanics"
Physikalische Zeitschrift der Sowietunion **3** (1933)64.
Precursor da integral de caminho de Feynman

- **Dirac, 1934**:

"Discussion of the infinite distribution of electrons in the theory of the positron"
Proc. Cambridge Philos. Soc. **30** (1934) 150.

Dirac e a Cosmologia

- Dirac, DEZ 1933 - The Nobel Lecture

  “A Theory of Electrons and Positrons”

- Dirac, ABR 1935

  O elétron e a constante cosmológica (de Sitter)

- Dirac, DEZ 1937

  “A new basis for Cosmology”.

O Filósofo, O estilista

- “Physical science and philosophy.”
  Nature **139** (1937) 1001.

- “The relation between Mathematics and Physics.”
  Proc. of the Royal Society (Edinburgh) **59** (1939) 122.

- “A new notation for Quantum Mechanics.”
  Proc. Cambridge Philos. Soc. **35** (1939) 416.

Dirac e a II Grande Guerra

- On **Lorentz** invariance in the quantum theory.
  PCPS **38** (1942) 193.
- The physical interpretation of quantum mechanics.
  PRSL **A180** (1942) 1.
- Quantum electrodynamics.
  Communications of the Dublin Institute for Advanced Studies, Series **A** **1** (1943) 1.
- Applications of quarternions to **Lorentz** transformations.
  Proceedings of the Royal Irish Academy, Section **A** **50** (1945) 261.
- On the analogy between classical and quantum mechanics.
  Review of Modern Physics **17** (1945) 195.
- Unitary representations of the **Lorentz** group. PRSL **A183** (1945) 284.

[Dirac, presente!] A QED de Dirac
e
novos portadores escalares de carga

- **Fermi-Majorana** (Cadernos de Majorana)
  Pauli-Weisskopf (1934)

- **Schwinger - Corben**, 1940, “mésotrons” carregados

- A QED na fase covariante: 1946 – 1952
  Schwinger, **Tomonaga [Dirac, presente!]**, Feynman.

[Dirac, presente!] Uma primeira “teoria de tudo”

1938 – O. Klein, “**On the Theory of Charged Fields**”

Encontro: “**New Theories in Physics**”

Varsóvia, SET 1938.

[Dirac, presente!] A década de ‘50

- **Salam**, **1952**:
  “Renormalized S-Matrix for Scalar QED”
  Phys. Rev. ***86*** *(1952) 731.*
  (Paper extraído de sua Tese de Doutorado.)
  Surge o potencial (de Higgs): $V(\varphi) \sim m^2 \varphi^2 + \lambda \varphi^4$.

- **Salam**, **1953**:
  “The Field Theory of Superconductivity”
  Progr. Theor. Phys. ***9*** *(1953) 550.*
  Bósons com carga elétrica devem auto-interagir.

- **Lição para a corrente fraca** (eletricamente) carregada:
  auto-interação de bósons vetoriais ~ extensão não-linear da QED.

Observação crucial e um novo horizonte se abre:
o potencial de Higgs.

Dirac e o Pré-Yang-Mills

- Dirac, NOV 1950:

  “A new meaning for gauge invariance in Electrodynamics”

- Dirac, 1952:

  “Les transformations de jauge em Eléctrodynamique”

  Annales de l’Insitut Henri Poincaré

  Importante informação:

  Sonja Ashauer, brasileira, defende seu Doutorado em Cambridge, em 1948, sob a orientação do Prof. Dirac, com um trabalho sobre a grande teoria que estava sendo gestada, a Eletrodinâmica Quântica.

Um grande marco: A Era Yang-Mills-Shaw

- Ronald Shaw <R.Shaw@hull.ac.uk>:

  Dear José,

  …….
  ……. A footnote on p.37 of Part II of my dissertation reads:

"The work described in this chapter (Ch.III) was completed, except for its extension in Section 3, in January 1954, but was not published. In October 1953, Yang and Mills adopted independently the same postulate and derived similar consequences."

But, although their publication date was in June 1954, Yang and Mills must have priority since it seems that their research was completed in 1953. [But see (*) at the end of this subsection.]

The idea for Chapter III of Part II came to me in a flash while reading a manuscript of Schwinger's, which I found left lying around in the Philosophical Library in Cambridge. In it Schwinger showed how invariance of the Lagrangian under general gauge transformations required the introduction of the electromagnetic field. This of course was not new (though possibly it was to me at that time), but Schwinger's manuscript used real spinors, and so the usual U(1) invariance appeared instead as SO(2) invariance. Being familiar with Kemmer's work on invariance under
"special" isotopic spin transformations it seemed to cry out to see what would happen if I changed Schwinger's (abelian) SO(2) to the (non-abelian) isospin SU(2).

Um grande marco: A Era Yang-Mills-Shaw

I showed my generalization to Salam in early 1954, but in a rather disparaging way, since I did not doubt at that stage that the new non-abelian gauge fields would require particles to have zero mass, and such particle did not appear to exist in nature. Later on in 1954, Salam showed me the paper by Yang and Mills. Salam still wanted me to publish my contribution, but I never did. On many occasions (the 1962 Istanbul Summer School on Group Theory in Physics, the Schrodinger Centenary Conference at Imperial College in 1987, ...) he publicised my independent discovery. In his Nobel Prize Lecture 1979, reprinted in Rev. Modern Phys. 52 (1980), 525-538, there are (see below) several references to Yang-Mills-Shaw theory. I have also recently come across a letter from Salam to me dated 1 Oct 1988 (in connection with the submission of a paper of mine to Proc. Roy. Soc.) in which he again refers to Yang-Mills-Shaw theory, and reminds me:

"I still remember asking you to publish this and you were very shy at that moment because you thought Yang-Mills had published it already although you had done the work independently."

However most physicists just refer to Yang-Mills theory --- and actually I am quite glad of this! *I like a quiet life, and would not have enjoyed being pestered throughout the decades by lots of queries from researchers expecting me to be up to date with latest developments.*

Um grande marco: A Era Yang-Mills-Shaw

- **Yang – Mills**, 28 JUN **1954**:
  "Conservation of Isotopic Spin and Isotopic Gauge Invariance"
  Phys. Rev. **96** (1954) 191 (publicado em 1º OUT 1954).

- Nas conclusões do paper ("Properties of the b-quanta"), a questão crucial: o gap de massa. (*Um dos problemas do Século XX*.)

- O paper ainda "não arrebata a platéia". Por quê?

- Ryoyu Utiyama, Phys. Rev. **101** (1956) 1597: geometrização.

- **Kibble, JMP 2 (1961) 212, « Lorentz invariance and the grav'l field ».**

A Conferência de Seattle, 1956

- **Lee – Yang**, **1956**:
  "Question of parity conservation in weak interactions"
  Phys. Rev. **104** (1956) 254
  22 JUN 1956, mas publicado em 1º OUT 1956.
  Prêmio Nobel de 1957 "for their penetrating investigation of the so-called parity laws which has led to important discoveries regarding the elementary particles."

- **[Dirac, presente!]** **Salam**, **1957**: **Simetria quiral**.
  "On parity conservation and neutrino mass"
  Il Nuovo Cim. Vol. V, No. **1** (1957) 299
  15 NOV 1956, mas publicado em 1º JAN 1957.

Salam redimensiona o papel crucial dos b-quanta de Y-M:

- ***Quiralidade preservada nas interações de gauge;***
- ***Flip de quiralidade nas interações tipo-Yukawa;***
- ***O papel dos escalares nas massa fermiônicas; mas ...***

“Conselho” de Pauli a Salam

- **Salam, 1956:**

“…..I gave Prof. Villars my paper. He returned the next day with a message from the Oracle (Pauli):

“Give my regards to my friend Salam and tell him to think of something better”.

This was discouraging, but I was compensated by Pauli’s excessive “kindness” a few months later, when ***Mrs. Wu’s , Lederman’s*** *and* ***Telegdi’s*** *experiments were announced showing that* ***left-right symmetry was indeed violated*** *and ideas similar to mine about chiral symmetry were expressed independently by Landau and Lee and Yang . I received Pauli’s first somewhat apologetic letter on 24 January 1957.”*

[Dirac, presente!] A Eletrodinâmica de bósons vetoriais carregados

Um problema nada trivial: matéria carregada com spin-1.

- **Komar** e **Salam**, **1960**:
  "Renormalisation problem for vector meson theories"
  Nucl. Phys. **21** (1960) 624.

- **Lee** e **Yang**, **1962**:
  "Theory of charged vector mesons interacting with the e. m. field"
  Phys. Rev. **128** (1962) 885.

- **Salam**, **1963**:
  "Renormalisable Electrodynamics of Vector Mesons"
  Phys. Rev. **130** (1963) 1287.

Resultados inconclusivos: alguma perturbadora inconsistência.

O que poderia estar faltando?

O que estariam indicando os acoplamentos não-mínimos?

Dirac – 1963: de novo, a elementaridade. Singletons (Dis e RACs) e a antecipação da conjectura de Maldacena

- **"A remarkable representation of the (3+2) de Sitter Group"**
  J. Math. Phys. **4** (1963) 901.

  Ideias que germinam neste paper:

  singletons confinados no Espaço de Minkowski,
  preons (Salam – Pati em 1974),
  correspondência gauge/gravidade.

- **1964: [Dirac, presente!]**
  Gell-Mann e Zweig: SU(3) e os quarks.

Um novo espaço-tempo, SUSY: resgatando Dirac - 1963

- Dirac e a busca de uma teoria quântica finita final:
  "*não deveria haver lugar para infinitos em uma teoria quântica realmente fundamental*."

Dirac e o esperado presente da Supersimetria:

- Salam – Strathdee: **Superespaço e Supercampos**
- **N=4-D=4 Super-Yang-Mills** (1982 – 1984)
- **N=2-D=4 Super-Yang-Mills** (1984 – 1986)
- **N=8-D=4 Supergravity** (1984 – 1986)

Dirac e suas sadias obsessões

- O **estruturalismo** e a crença na **elementaridade**
- O **elétron**, sua estrutura e seu possível EDM
- O **setor magnético de Born – Infeld**
- A **constante de estrutura fina** a partir de uma teoria fundamental
- A busca de uma **teoria quântica finita**
- **A incessante procura por novas matemáticas.**

Agradecendo ao Novello pela organização do evento e pelo convite.

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- www.professorglobal.com
  Barra: Física Quântica

- Para mais informações:
  República Fundamentalista do Diracstão,
  CBPF, 3'ro andar, Ala – D.