

July 2, 2021

Some Perspectives and Questions on String Theory

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Strings 2021, ICTP-SAIFR Sao Paolo (virtual)

This has been a wonderful conference taking place in very difficult circumstances. The organizers have devised an imaginative format that has allowed substantial time for stimulating discussions on every aspect of the subject.

The topics covered by Strings conferences encompass ever widening areas of theoretical and mathematical physics, which makes it difficult to present a perspective that does justice to its richness. Here I will illustrate this by comparing the present state of the subject with its origins in the late 1960's

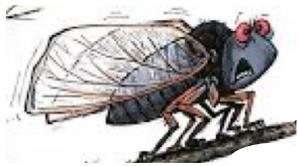
I came to Princeton as a postdoc in 1970. A notable event of that year was the emergence of trillions of Brood X cicadas that have a 17-year life cycle*. They live underground for precisely 17 years before emerging, mating, giving birth and dying.

This year, 51 years later, their great grandchildren have emerged and are discovering a radically different Universe in which there are many new concepts and many old concepts have been refined and reinterpreted.

* Prime number selection of cycles in a predator-prey model [Eric Goles](#), [Oliver Schulz](#), [Mario Markus](#) *Complexity* 6 (4):33-38 (2001).



1970: An intelligent Princeton Cicada emerges from his/her 17-year hibernation.



HE/SHE REMEMBERS **1953:** QUANTUM ELECTRODYNAMICS, EARLY PROPERTIES OF NUCLEONS AND MESONS – ISOSPIN, STRANGENESS

By **1970** THINGS HAD TRANSFORMED. SEVERAL QUITE DISTINCT SETS OF IDEAS:

- A WEALTH OF **EXPERIMENTAL DATA** ON THE **STRONG INTERACTION (esp. PION-PROTON SCATTERING)**.

THEORETICAL IDEAS: THE ANALYTIC S-MATRIX, QUARKS, CURRENT ALGEBRA, ...

Introduction to Complex Orbital Momenta.

T. REGGE

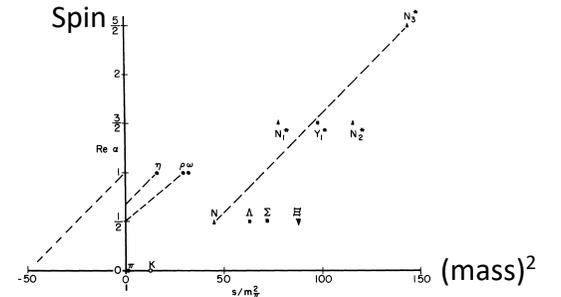
Max-Planck-Institut für Physik und Astrophysik - München (*)

(ricevuto il 18 Luglio 1959)

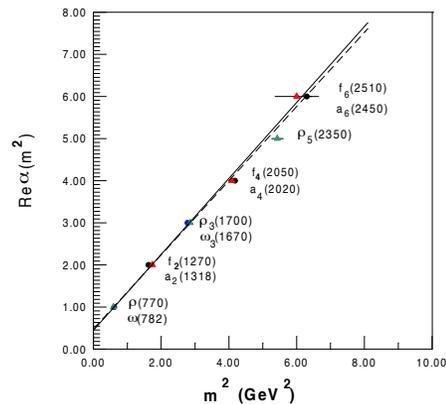
REGGE POLES AS CONSEQUENCES OF ANALYTICITY AND UNITARITY

S. Mandelstam

University of Birmingham, Birmingham



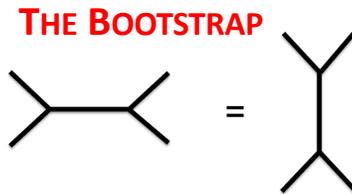
COMPLEX ANGULAR MOMENTA
in potential theory **REGGE (1959)**



REGGE POLES in relativistic amplitudes
MANDELSTAM (1962)

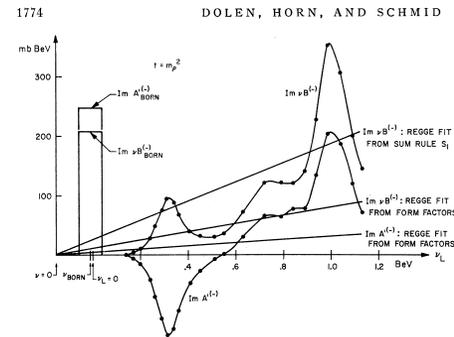
CHEW-FRAUTSCHI PLOT (1962)
NUCLEONS

HAGEDORN SPECTRUM (1965)



DUALITY: SUM OF RESONANCES
= SUM OF REGGE POLES

$$A_{\pi^+\pi^-\rightarrow\pi^+\pi^-}(s, t) = \frac{\Gamma(1 - \alpha_\rho(t)) \Gamma(1 - \alpha_\rho(s))}{\Gamma(1 - \alpha_\rho(s) - \alpha_\rho(t))}$$



FINITE ENERGY SUM RULES (1967);

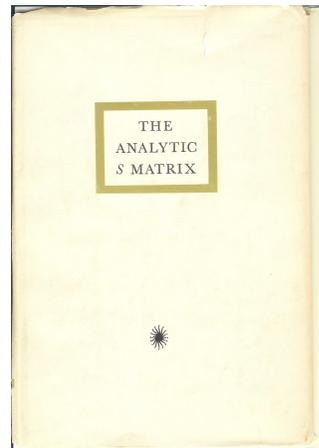
VENEZIANO MODEL (1968)

2021

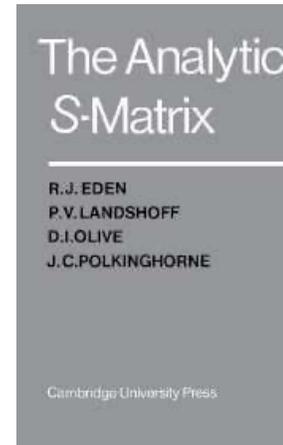
CHEW-FRAUTSCHI PLOT
RHO MESON (recent)

- This was also the era of early work on applications of **YANG-MILLS THEORY (1954)** leading eventually to the **ELECTRO-WEAK THEORY (1967)**, (**QCD** and **ASYMPTOTIC FREEDOM. (1973)**).
 - **COSMOLOGY:** had taken off **THE BIG BANG, PULSARS, QUASARS,**
 - **EINSTEIN GRAVITY:** **BLACK HOLES, GRAVITATIONAL RADIATION**
- } **LARGELY DISCONNECTED FROM PARTICLE PHYSICS**

Spot the difference!



G. Chew 1966



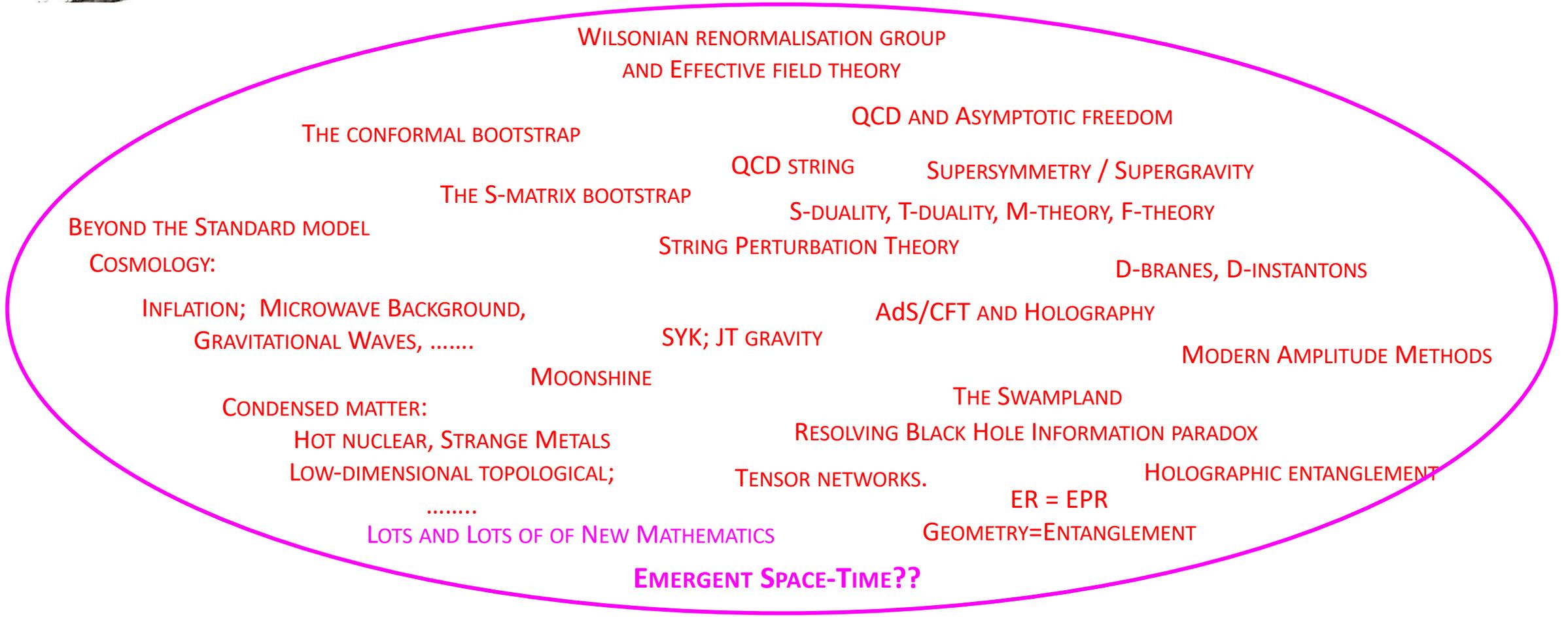
E.L.O.P. 1966

Immortal opening lines of the preface !! :
“One of the most remarkable discoveries in elementary particle physics has been that of the existence of the complex plane.”

2021:



A great grand-child cicada emerges from her 17-year hibernation to attend Strings 2021 and is impressed by the very wide range of topics and the outstanding talks. Over the past 51 years there has been a remarkable linking of a multitude of subjects stimulated largely by ideas in string theory.



THE STRING THEORY UNIVERSE

Goes far beyond the original aims of string theory

A FEW QUESTIONS FOR OTHERS TO ANSWER:

- Is there a background independent formulation of holography?
If so, what would that teach us about quantum gravity or QFT?
- Are “fundamental strings” “fundamental”? **OR** Is String Theory a theory of strings?
- Is there is a UV complete description of the QCD string that describes point-like deep inelastic and fixed angle scattering?
- Is inflation natural in string motivated cosmology?
- Can particle physics progress beyond the standard model without accelerators with energies greater than that of the LHC?
- Can future cosmology experiments usefully replace accelerator experiments?

Strings 2021 has been fantastic.

Thank you ICTP-SAIFR