Istituto Nazionale di Fisica Nucleare
Piano Triennale 2019-2021
Auditorium Manzoni, Bologna, 12-12 Ottobre 2018

THE GAP AND THE ORIGIN OF THE FUNDAMENTAL FORCES
(GRAVITY AND QED, QFD, QCD)

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Bologna, 12 October 2018

Abstract

The energy level where the best values of the three fundamental gauge couplings ($\alpha_1, \alpha_2, \alpha_3$) converge is at least two orders of magnitude below the Planck energy level. The existence of this Gap could imply that the gravitational force

'comes into being'

before QED, QFD and QCD.

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The most interesting consequence of the Gap would then be the existence of matter whose charge is only the gravitational charge.

If this is so, events should be detected where only gravitational waves are produced.

Primordial black holes (PBHs) would be produced much more frequently than standard black holes (SBHs) since SBHs would be '*derivative*' effects produced later, after matter made with protons, electrons, neutrons, and stars can exist.

Collisions between PBHs generating only gravitational waves would be more frequent than SBHs collisions.

THE GAP AND THE ORIGIN OF THE FUNDAMENTAL FORCES

We would like to call attention on the energy Gap which exists between the energy level E_{GUT}

[where the three gauge couplings
α_1 (QED),
α_2 (QFD) and
α_3 (QCD) converge
towards a common origin, α_{GUT}]

and the Planck energy level, E_{Planck}.

This Gap could be the first evidence for the origin of the fundamental forces to be at two different energy levels.

The first energy level being the one where the gravitational force "*comes into being*": in 1977 John Wheeler recalled [1] that we should care to study how "*the laws come into being*".

Since no one has been able to solve this problem, the solution has been given for granted: all fundamental forces start at the same instant with a Big Bang.

In this case the Gap should not exist, due to the fact that all forces start at the same energy level.

The existence of the Gap opens new problems on the study of the gravitational forces. For example the study of the spectrum of the primordial black holes (PBHs) produced before

QED, QFD and QCD

"*come into being*".

These PBHs possess only the gravitational charge. The first PBH is the smallest object in the Universe, with mass 10^{-5} g and radius 10^{-33} cm: the Planck PBH.

During the existence of the Gap no other forces could be active. Only gravitational waves and particles with gravitational charge exist.

The mass spectrum
of the PBHs
cannot be derived
from
fundamental principles
but described
by models [2].

Let us not forget that the masses of all particles of the Standard Model of Subnuclear Physics [3] are not predicted but experimentally measured. This is why we should be prepared to experimentally determine the masses of the PBHs, as already started to be done by the LIGO-VIRGO collaboration [4].

The existence of the Gap is illustrated in Fig. 1.

The present value of E_{GUT} is based on the most exact study of the evolution with energy of the three gauge couplings (α_1, α_2, α_3) [5].

It should not be forgotten that during more than ten years (from 1979 to 1992), no one realized that the energy threshold for the existence of the superworld (i.e. the threshold for supersymmetry breaking $E_{SUSY}^{(\neq)}$) was strongly dependent on the running of the masses.

Until 1992 it was so.

The then best theoretical prediction [6] for the energy threshold of the superworld,

$$E_{SUSY}^{(\neq)},$$

was calculated to be 21 TeV.

The authors of this prediction computed, as everybody else, the energy threshold

$$E_{SUSY}^{(\neq)}$$

using only the running of the gauge couplings

$$(\alpha_1, \alpha_2, \alpha_3)$$

which corresponds to neglecting [6] nearly three orders of magnitude in the energy threshold for the discovery of the lightest particle of the superworld (LPS), as proved in Ref. 7.

The running of the masses is now called the EGM effect (from the initials of evolution of gaugino masses, see later). Since then many other measurements of the gauge couplings at higher energies have been obtained; the values of α_1, α_2, α_3 have been confirmed [8] and the Gap, reported in Fig. 1, remains as it was in 1992 [5].

The consequences of the Gap in understanding the origin of our Universe is one of the most interesting problems in front of us.

The first question is how the Universe would be if only gravitational forces were active. There would be neither stars nor standard black holes (SBHs) (see later).

In this Universe only gravitational waves could exist and masses with only one type of charge: the gravitational one.

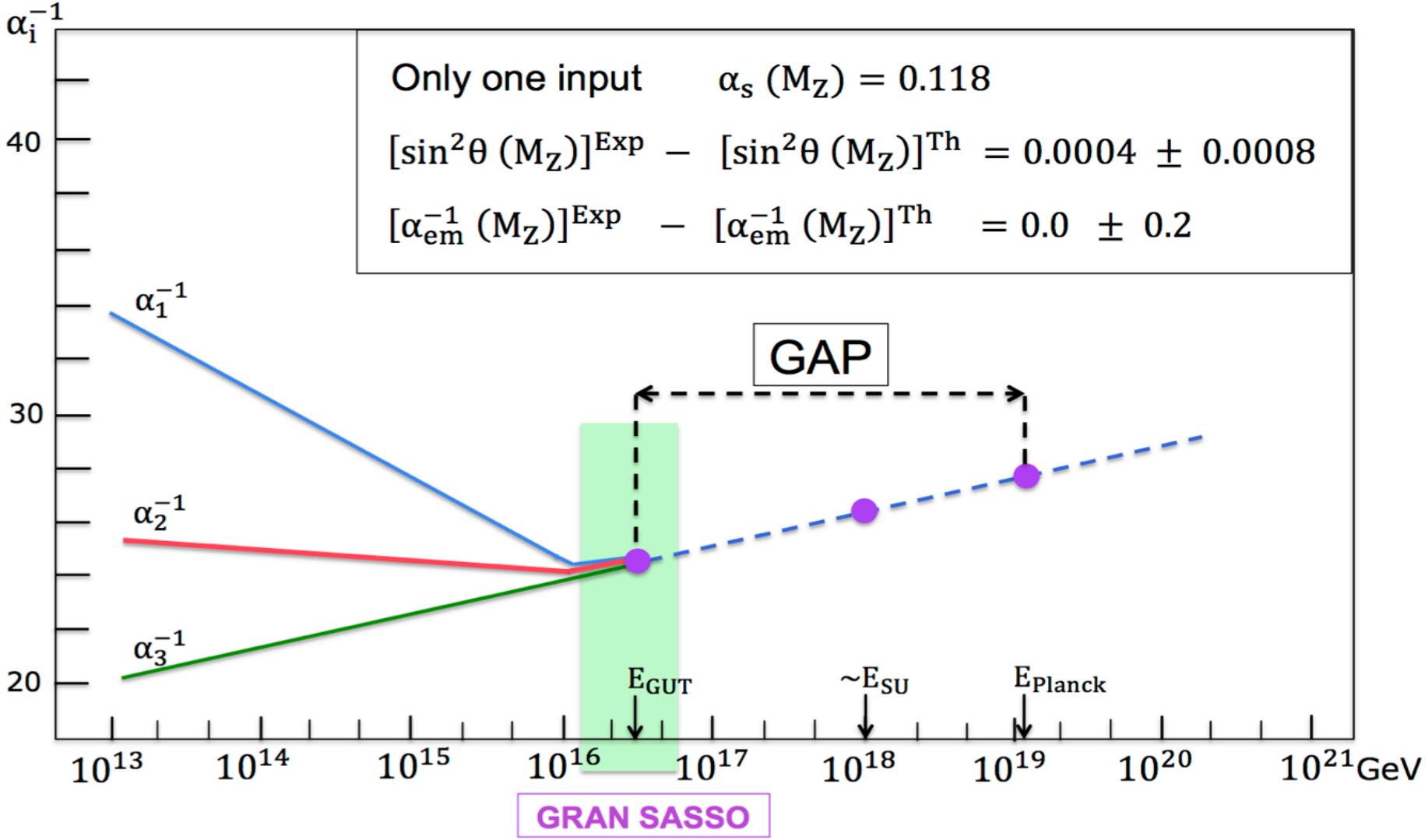

Fig. 1: The Gaps between the Planck energy, E_{Planck}, and the two energy levels, E_{GUT}, where the three gauge couplings converge, and E_{SU}, where the RQST (Relativistic Quantum String Theory) [9] puts the origin of the gravitational forces [5]. The Gran Sasso label indicates the biggest underground laboratory to study neutrinos and cosmic energies of extremely high values.

Between the two extreme levels,

E_{GUT} and E_{Planck},

there is the energy level E_{SU}, where the Relativistic Quantum String Theory (RQST) [9] puts the origin of the gravitational forces, i.e. the string unification scale E_{SU}.

Superstring theory does not provide the fundamental length.

This is derived from the Planck length.

The string unification coupling, α_{SU}, where all gauge interactions join with gravity rather than being an arbitrary parameter, is determined by the vacuum expectation value (VEV) of a scalar field, the so-called dilaton $\phi(t)$ (for a review see Ref. 10).

Superstring theory does not provide the VEV of the dilaton.

This is taken to be equal to α_{GUT} at the E_{GUT} scale.

Taking into account the RQST it is necessary to multiply

$$E_{Planck} \text{ by } \sqrt{\alpha_{SU}} \ .$$

The result goes down to

$$E_{SU} \simeq 10^{18} \text{ GeV}.$$

and the energy interval of the Gap becomes

$$(10^{-16} \div 10^{-18}) \text{ GeV}.$$

The conclusion is that E_{SU} is not a spectacular result of RQST. It is very strongly related to E_{Planck}.

Few words on the study of the pre-Big Bang. Gabriele Veneziano and collaborators [11] proposed the existence of a stochastic background of gravitational waves.

These waves are coming from the Universe which existed long before the '*quantum of time*' in what they call a pre-Big Bang phase. The stochastic background has a characteristic frequency spectrum [12], several orders of magnitude higher than that of standard inflationary cosmology.

This '*gravitational light*' would be the effective radiation emitted at times of the order of the Planck time ($\simeq 10^{-43}$s).

Another interesting effect is the amplification of electromagnetic fluctuations, due to the drastic variation of α_{SU}, which could provide the long-sought explanation for the observed galactic magnetic fields [13].

All these ideas have no effects on the existence of the Gap.

The only effect is the production of a background of gravitational waves.

And now back at the time of the 1979 EPS Geneva Conference, when

"*the three gauge couplings,*

$\alpha_1, \alpha_2, \alpha_3,$

were not converging in a point but in a sort of triangle".

These words are of Rudolf Mössbauer [14]. The three gauge couplings

$$(\alpha_1, \alpha_2, \alpha_3)$$

do converge towards a unique value

$$\alpha_{GUT} \simeq \frac{1}{25}$$

at the energy $\alpha_{GUT} \simeq 10^{16}$ GeV if the existence of supersymmetry is introduced [15] in the evolution equations of

$$\alpha_1, \alpha_2, \alpha_3.$$

As mentioned before the energy evolution of the three couplings

$$\left.\begin{array}{l}\alpha_{13}\,(q^2)\\ \alpha_{2}\,(q^2)\\ \alpha_{3}\,(q^2)\end{array}\right\} \qquad (1)$$

had never before been performed with the new condition [7, 16] based on the energy dependence, not only of the gauge couplings themselves, but also of the masses: i.e. the

EGM (evolution of gaugino masses) effect [7, 16-18] mentioned before.

The EGM effect
produces nearly
three orders of magnitude,
a factor $(700)^{-1}$,
for the threshold of
supersymmetry breaking,
$E_{SUSY}^{(\neq)}$ [18].

Suppose the convergence of the three couplings (α_1, α_2, α_3) is computed taking into account the evolution of each coupling with q^2, neglecting the variation of the masses associated with the physics of the given gauge group, i.e. U(1) for α_1, SU(2) for α_2 and SU(3) for α_3. Suppose the prediction is $E_{SUSY}^{(\neq)} = 700$ TeV.

Using the same model this prediction becomes 1 TeV, if the EGM effect [7, 16-18] is included: the search for the lightest supersymmetric particle becomes possible at LHC.

The EGM effect is important for the lowest limit of the Gap, while the upper limit is given by the Planck energy level.

In the energy interval $(10^{16} \div 10^{18})$ GeV the Universe consists only of what the gravitational forces can do in terms of '*primary*' effects [1], not '*derivative*'.

The primary effects are the 'primordial Schwarzschild objects' (P-SCH-objects) discussed in Ref. 19.

In this paper we pointed out that our Universe seems to be the proof that a P-SCH-object, starting from the Planck Universe, can expand its radius by something like 62 orders of magnitude following the conditions dictated by the Schwarzschild solution of the Einstein equation.

The Einstein equation and the Schwarzschild solution ignore the existence of $SU(3) \times SU(2) \times U(1)$. The convergence of the three gauge couplings (α_1, α_2, α_3) at E_{GUT} is nearly two orders of magnitude below E_{SU}.

In this energy Gap the P-SCH-objects are produced, which could indeed be the seeds of all galaxies. If we could see the inner structure of these objects we would find that the matter they are made of is not the one familiar to us, i.e. a matter made with protons, electrons and neutrons (p, e, n).

The P-SCH-objects, as said before, are made with matter whose charge is only the gravitational charge.

Their size is not necessarily confined within the cosmological horizon.

Inflationary scenarios allow for even larger PBHs, the so-called super horizon PBHs [20].

Standard black holes (SBHs) [21] are produced later, when QED, QFD and QCD are switched on.

SBHs are actually due to '*derivative*' effects produced by matter made with (p, e, n).

All we can do is to study the collisions of two black holes.

If they are P-SCH-objects [19], these collisions would generate only gravitational waves.

Present technologies allow to observe gravitational waves [4].

If these gravitational waves are not accompanied by electromagnetic waves and/or neutrinos, this would be evidence that P-SCH-objects exist.

These P-SCH-objects could solve the problem of the missing mass in the Universe, for the very simple reason that P-SCH-objects are directly produced at extremely high energy when only the gravitational forces are active [19].

Their number should be much larger than the number of SBHs since the production mechanism of the latter is not '*primary*' but '*derivative*' [1].

SBHs are the result of a succession of secondary processes at much lower energies, occurring after matter made with protons and electrons, including the subsequently produced neutrons and stars, can exist.

The problem is to find out if the origin of the fundamental forces is all at once in the Big Bang or if the origin is in two steps.

The existence of the Gap is a result which implies that the gravitational force "*comes into being*" before QED, QFD and QCD.

The "*comes into being*" bring us back to 1977 when John Wheeler, after many discussions, was invited to give a series of lectures in Italy.

In the lecture notes [1] on page 11 he writes: "*It is preposterous to think of the laws of physics as installed by a Swiss watchmaker to endure from everlasting to everlasting.... The laws must have come into being*".

The mechanism of how "*The laws must have come into being*" should indeed be studied; it was a problem in the discussions with Patrick Blackett and his friend Bertrand Russell [22], in the fifties.

After many decades it has been abandoned, since no one has been able to contribute towards a description of how the fundamental forces

"*come into being*".

On page 11 Wheeler continues: "*Therefore they could not have been always a hundred percent accurate. That means that they are derivative, not primary*".

And on page 44: "*Of all strange features of the Universe, none are stranger than these: time is transcended, laws are mutable, and observer-participancy matters*" [1].

These notes
allow to understand what
John Wheeler
elaborated after
many successful decades
of activities in physics.

Here is a synthesis of our discussions [1]: "*When a new idea comes in, we physicists should not start writing formulae but translate the new idea in terms of effects to be first imagined in terms of known facts. Formulae must come later*". The wording is not exact: the conceptual meaning is exact.

This is the reason why we have written this paper, going on with effects to be imagined, before a mathematical formalism can be worked out.

Following John Archibald Wheeler [1], the starting point is the new idea (the gravitational force comes into being before the other fundamental forces) first imagined in terms of known facts: the existence of the Gap.

The mathematics needed to describe how the Gap can be connected with the P-SCH-objects [19] and how the mass spectrum of PBHs can be derived and connected with the origin of the dark matter [2] must come later [23].

References

[1] *Frontiers of Time*
J.A. Wheeler, North-Holland, Amsterdam (1979), and private discussions.

[2] *Primordial Black Holes as Dark Matter*
B. Carr, F. Kühnel and M. Sandstad, *Nordita-2016-83*, arXiv: 1607.06077v3.

[3] A. Zichichi, *Subnuclear Physics: The first 50 Years: Highlights from Erice to ELN*, eds. O. Barnabei, P. Pupillo, F. Roversi Monaco (a joint publication by University and Academy of Sciences of Bologna, Italy, 1998); *World Scientific Series in 20th Century Physics*, Vol. 24 (2000).

[4] *The First Experimental Evidence for the Existence of Gravitational Waves*
A. Giazotto, in Proceedings Subnuclear Physics Erice School–2016 The New Physics Frontiers in the LHC-2 Era, World Scientific, to be published;
Observation of Gravitational Waves from a Binary Black Hole Merger
B.P. Abbott et al. (Virgo, LIGO Scientific), Phys. Rev. Lett. 116, 061102 (2016), arXiv: 1602.03837.

[5] *A Study of the Various Approaches to M_{GUT} and α_{GUT}*
F. Anselmo, L. Cifarelli and A. Zichichi, Nuovo Cimento 105A, 1335 (1992); Searching for the Superworld, S. Ferrara and R.M. Mössbauer (eds), World Scientific Series in 20th Century Physics Vol. 39 (2007).

[6] *A Detailed Comparison of LEP Data with the Predictions of the Minimal Supersymmetric SU(5) GUT*
J.R. Ellis, S. Kelley, D.V. Nanopoulos, *Nucl. Phys.* B373, 55 (1992), preprint CERN-TH/6140-91.

[7] *The Evolution of Gaugino Masses and the SUSY Threshold*
F. Anselmo, L. Cifarelli, A. Petermann and A. Zichichi, *Il Nuovo Cimento* 106A, 581 (1992).

[8] *2015 Review of Particle Physics*
K.A. Olive *et al.* (Particle Data Group), *Chin. Phys. C,* 38, 090001 (2014) and 2015 update.

[9] Beyond Relativistic Quantum String Theory
G. 't Hooft, in Proceedings Subnuclear Physics Erice School–2012, Vol. 50 (World Scientific, 2014).

[10] G. Veneziano, *An Amusing Cosmology from the String Effective Action* in *Effective Theories and Fundamental Interactions*, in Proceedings Subnuclear Physics Erice School–1996, Vol. 34 (World Scientific, 1997) p. 300.

[11] *Scale Factor Duality for Classical and Quantum Strings*
G. Veneziano, *Phys. Lett.* B265, 287 (1991);
Pre-Big-Bang in String Cosmology
M. Gasperini and G. Veneziano, *Astropart. Phys.* 1, 317 (1993).
For a complete collection of papers on the PBB scenario see: *http://www.to.infn.it/~gasperin/*.

[12] *Relic Gravitational Waves from String Cosmology*
R. Brustein, M. Gasperini, M. Giovannini and G. Veneziano, *Phys. Lett.* B361, 45 (1995).

[13] *Primordial Magnetic Fields from String Cosmology*
M. Gasperini, M. Giovannini and G. Veneziano, *Phys. Rev. Lett.* **75**, 3796 (1995).

[14] *Searching for the Superworld*
R.M. Mössbauer, World Scientific Series in 20th Century Physics Vol. 39, eds. S. Ferrara and R.M. Mössbauer (2007), p. 4.

[15] New Developments in Elementary Particle Physics
A. Zichichi, *Rivista del Nuovo Cimento* **2**, n. 14, 1 (1979). The statement on page 2 of this paper, "*Unification of all forces needs first a Supersymmetry. This can be broken later, thus generating the sequence of the various forces of nature as we observe them*", was based on a work by A. Petermann and A. Zichichi in which the renormalization group running of the couplings using supersymmetry was studied in order to obtain the convergence of the three couplings at the same point. This work was not published, but perhaps known to a few. The statement quoted is the first instance in which it was pointed out that supersymmetry should play an important role in the convergence of the gauge couplings.

[16] *The Simultaneous Evolution of Masses and Couplings: Consequences on Supersymmetry Spectra and Thresholds*
F. Anselmo, L. Cifarelli, A. Petermann and A. Zichichi, *Il Nuovo Cimento* 105A, 1179 (1992).

[17] *The Effective Experimental Constraints on* M_{SUSY} *and* M_{GUT}
F. Anselmo, L. Cifarelli, A. Petermann and A. Zichichi, *Il Nuovo Cimento* 104A, 1817 (1991).

[18] *Understanding Where the Supersymmetry Threshold Should Be*
A. Zichichi from Proceedings of the Workshop on *Ten Years on SUSY Confronting Experiment,* CERN, Geneva, Switzerland, 7-9 September 1992, CERN-PPE/92-149, CERN/LAA/MSL/92-017 (7 September 1992) and CERN-TH 6707/92-CERN-PPE/92-180 (CERN, Geneva, 1992), 94. All References to these works are in the Special Volume *Searching for the Superworld*, S. Ferrara and R.M. Mössbauer (eds), World Scientific Series in 20th Century Physics Vol. 39 (2007).

[19] *The mass and the vacua of our Universe following Planck and Schwarzschild*
A. Zichichi, *Eur. Phys. J. Plus*, 131, 359 (2016); DOI: 10.1140/epjp/i2016-16359-0.

[20] *Super-Horizon Primordial Black Holes*
T. Harada and B.C. Carr, *Phys. Rev.* D72 (2005) 044021.

[21] Latest News from Black-Holes Physics
G. 't Hooft, in Proceedings Subnuclear Physics Erice School–2010, Vol. 48, World Scientific (2013); *Quantum Gravity without Space-Time Singularities or Horizons*, G. 't Hooft, in Proceedings Subnuclear Physics Erice School–2009, Vol. 47, World Scientific (2011).

[22] A Lesson for the Future of Our Science. My Testimony on Lord Patrick M.S. Blackett
A. Zichichi (World Scientific, 2016).

[23] *The Evolution of the Universe*
A. Zichichi, to be published.