

# The principle of global relativity

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New Physics Directions in the LHC era and beyond  
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References:

J.J. van der Bij, Acta Phys. Pol. B52, 627 (2021), (Veltman 90)

van der Bij podcast Freiburg The Principle of Global Relativity

## 7th Triangle meeting Utrecht-Paris-Roma Nikhef, Amsterdam januari 1981

Already then it was clear that the standard model is basically right, but people were dissatisfied. Important at the time was the question of unification and the question why there were three generations. The last question was quickly shelved; it appeared unapproachable. One wanted to understand the masses as well, also fairly hopeless. In the end the main focus became the naturalness problem, which is not obviously a real problem.

- ▶ Simplicity, M. Veltman
- ▶ Fixed point, J. Iliopoulos
- ▶ Naturalness, G. 't Hooft

## Hierarchy problem

Is it real or just an artefact of our calculational methods?

BPHZ  $m_\gamma \approx M_{Pl}$  , Pauli-Villars not.

Indication for grand unification!?

Dimensional regularization,  $m_H \approx m_{GUT}$ .

But unphysical, integral negative, integrand everywhere positive.

More scientific definition by G. 't Hooft: a parameter can be small when putting it to zero enhances the symmetry of the theory.

So Higgs mass unnatural because there is no such symmetry (m4).

People thought at the time the fermion masses were small compared to the weak scale. Since the top mass is heavy, the idea is no more attractive. By now it is clear that naturalness is no principle of nature.

## Naturalness as a principle

Most of the focus was on supersymmetry.

No quadratic divergences and no renormalization of the superpotential. How logical? Did this really solve the problem?

Pro: Fine tuning only once at the tree level.

Contra: nature is quantummechanical.

Pro: Dark matter candidate.

Contra: not from supersymmetry but from R-parity.

A link with the theory of everything:  $N=8$  supergravity, heterotic string, M-theory and landscape.

Finally as an anti-principle to ignore all other principles.

Example: black holes at the LHC.

All gone now: cosmological constant positive. Also nothing found.  
Therefore we need a new paradigm (see P5 report).

## Paradigm shift

Dear Fabiola,

I want to congratulate CERN for the great running of the machine and the brilliant work of the detectors. I think the results are great, I have rarely seen such a convincing null-experiment. I am sure this will lead to the long overdue paradigm-shift away from the view "the standard model is wrong and we will have to see what is beyond" towards the view "we know the standard model is true and we have to understand why".

In the attachment I give you my answer.

good luck, Jochum

(2016)

# Three steps of Philosophia naturalis

- ▶ There are natural laws
- ▶ we have to determine, what they are
- ▶ we have to understand why the laws are the way they are.

As Einstein said: I am interested to know whether God had a choice when He created the world.

# Is there a reason for the choice of gauge group and representations?

Phys. Rev. D76, 121702 (R) (2007);

General Relativity and Gravitation 43, 2467 (2011).

I. Rabi: Who ordered that?  
on the discovery of the muon

A. Einstein: Did God have a choice when He created the world?

## Anomalies !

L. Alvarez-Gaume, E. Witten, gravitational anomalies;  
Nucl. Phys. B234 (1986), 309.

We do not know under what conditions such phenomena occur in general relativity.

E. Witten, global gravitational anomalies;  
Commun. Math Phys. 100 (1985), 227.

The choice of  $S^4$  corresponds to treating four dimensional space time as Minkowski space. In the long run, a more delicate choice will be necessary to accomodate cosmological considerations. It may be that eventually global anomalies will have cosmological applications, restricting the large scale topology of space-time.

J.J. van der Bij:

Apparently it is the opposite, all topology is allowed, but the particle types are restricted. The topology I use is the one with few observational limits.

## Principle of global relativity

Gravity is a geometrical theory. The Einstein equations allow for different topologies. The matter fields live in these geometrical backgrounds. The matter equations should be consistent with any form of compactification (or more general "every" topology) of spacetime consistent with the Einstein equations.

This allows for topological anomalies that can constrain the matter content!

## Construct a suitable cosmological model

Assume an inflationary Bianchi-I cosmology with topology of the universe  $M_3 \times S_1$ .

The radius of the circle may be too large to see the topology at the present time

However a preferred direction may be visible; there appears to be an alignment of low multipoles along a preferred axis in the data.

Going back in time we assume the direction of the circle shrinks faster than the other directions and reaches the Planck length, where it disappears. So the early universe was 2+1 dimensional. This is a conservative assumption compared to standard cosmology, where the universe starts in a point.

## Three dimensional gravity

$$\mathcal{L} = -(1/\kappa^2)\sqrt{g}R - \frac{i}{4\kappa^2\mu}\epsilon^{\mu\nu\lambda}(R_{\mu\nu ab}\omega_\lambda^{ab} + \frac{2}{3}\omega_{\mu a}^b\omega_{\nu b}^c\omega_{\lambda c}^a).$$

$$q_{gr} = \frac{6\pi}{\mu\kappa^2} \text{ must be integer}$$

## Renormalization

R.D. Pisarski, S. Rao, J.J. van der Bij; Phys. Lett. B179, 87 (1986).

$$q_{gr}^{ren} = q_{gr}^0 + \frac{1}{8}N_g \text{ sign}(m_g) - \frac{1}{16}N_f \text{ sign}(m_f)$$

$N_g$  is the number of vector bosons

$N_f$  is the number of fermions

assume  $q_{gr} = 0$  (Einstein equations)

consistency:  $N_f \mp 2N_g = 0 \pmod{16}$

## Stronger conditions

isotropization:  $q_{gr}^{ren} = 0$

vectors and fermions separately consistent:

$$N_g = 0 \pmod{8}$$

$$N_f = 0 \pmod{16}$$

In combination      vectors  $SU(5)$ : 24  
                             fermions  $SO(10)$ : 16

$$2 \times 24 - 3 \times 16 = 0$$

Basically unique if also:

- 1) fermions automatically anomaly free, i.e. no  $SU(n)$ :
- 2) fermions in fundamental representation

## Towards the Standard Model

- ▶ Symmetry breaking:

$SU(5)$  decomposition:  $16 = 10 + \bar{5} + 1$ .

$$SU(3) \rightarrow +, \quad SU(2) \rightarrow -, \quad U(1) \rightarrow +$$

$$10 \rightarrow +, \quad \bar{5} \rightarrow -, \quad 1 \rightarrow -$$

$$2 \times (8 - 3 + 1) - 3 \times (10 - 5 - 1) = 0$$

possible:  $SU(5) \rightarrow SU(3) \times SU(2) \times U(1)$

impossible:  $SU(5) \rightarrow SU(4) \times U(1)$

- ▶ Conclusion: only minimalistic extensions possible.
- ▶ Questions: more conditions, other compactifications, underlying structure, quantum gravity?

## $SU(5)$ Unification

European Physics Letters (EPL), 100, 29003 (2012).

Extra fermion fields are needed, but multiple of 16.

Solution: a Dirac **24**

Symmetry breaking by **24** Higgs field.

Unification is easy, both **F** and **D** term of  $SU(5)$  possible.

$$\mathbf{F}_{abc} = \mathbf{Tr}([T_a, T_b]T_c)$$

$$\mathbf{D}_{abc} = \mathbf{Tr}(\{T_a, T_b\}T_c)$$

$$\mathbf{24} = (\mathbf{8}, \mathbf{1}, \mathbf{0}) \oplus (\mathbf{1}, \mathbf{3}, \mathbf{0}) \oplus (\mathbf{3}, \mathbf{2}, -\mathbf{5}/\mathbf{6}) \oplus (\mathbf{3}, \mathbf{2}, \mathbf{5}/\mathbf{6}) \oplus (\mathbf{1}, \mathbf{1}, \mathbf{0})$$

Dark matter candidate: A Dirac triplet with mass  $1.9 \text{ TeV}$ .

## Phenomenology

$$\mathbf{Triplet} = (\mathbf{T}^+, \mathbf{T}^0, \mathbf{T}^-)$$

The neutral field is the dark matter.

The charged field is heavier by  $166 \text{ MeV}$ , due to the Coulomb energy. Decay in missing energy plus soft pion.

Can this be seen?

HL-LHC : NO !

Direct search : NO !

FERMI: strong constraints , but very large uncertainties due to halo models.

Cerenkov Telescope Array (CTA): should see this without much problems !!

## Future history ?? ;-)

Ether

Dark Matter

Michelson-Morley

XENON

special relativity

global relativity