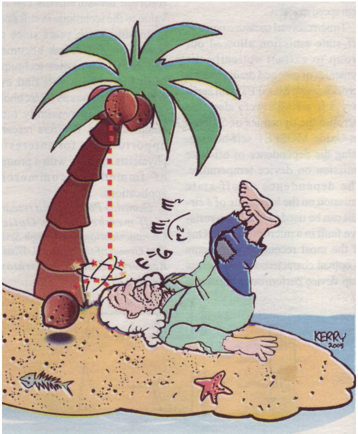
Too many too self confident talks about ideas beyond the Standard Model led me two years ago to give a special

Aprils Fool Talk

outside of my usual field.
The outcome was a conviction that there is a

serious point

which will presented here.



Why gravity was not discovered in Tahiti.

Novel ideas about emergent vacua

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Annecy, March 29, 2011

Simple Arguments for Emergent Vacua

Most people probably agree:

- QCD and the electroweak gauge theories are some of the biggest theoretical achievements of our times.
- Spontaneous symmetry breaking in a theory with running coupling constants is a beautiful concept to allow for mass scales far away from the grand unification scale.

However, the mass transfer concept does not work for the scalar electroweak Higgs mass. It is the hierarchy problem.

However, as

- everything seemed almost correct and
- all masses had to originate in the GUT scale

one dared to accept drastically new concepts like *supersymmetry* or *extra dimensions*.

What changed since then?

- Particle physics and cosmology is no longer considered as separable.
- The meV dark energy scale of cosmology more or less exactly corresponds to the neutrino mass scale.

So there is no need to directly connect to a GUT mass scale. The justification for introducing the drastically new theories no longer exist.

It is widely assumed that the dark energy has something to do with the vacuum condensate and it is plausible that such a condensate is responsible for the observed masses.

The neutrino mass is, of course, considered as special. The assumption is that supersymmetry or extra dimension explain the usual masses and that an unusually small Majorano neutrino mass arises from a sea-saw mechanism.

However, the neutrinos are not the only fermions with special masses and the **spread in fermion masses** is so far not understood.

Here, with the dark energy scale and the GUT scale one has a **two scale situation**. To produce intermediate scales is then comparatively easy. Combination of powers can produce powers of intermediate scales.

Hence, the spread of the masses is no argument against the concept. It is actually helpful.

A cosmological example for possible power combinations is the **Zeldovich relation**

$$H \cdot M^2_{\mathrm{Planck}} \propto \lambda^2_{\mathrm{QCD}}$$

Here the Hubble constant H is related to the condensate mass density and λ_{QCD} is the QCD mass scale.

Relations with power combinations are well established in chiral perturbation theory. The observed pseudo-scalar meson mass is

$$M^2_{\mathrm{pion}} = B_{\mathrm{condensate\ scale}} \cdot (\mathrm{fermion\ mass\ scale})$$

This relation can be applied to massive bound state of GUT mass fermions

$$M_{\mathrm{bound}} = (3\mathrm{me}V \cdot 10^{15}\mathrm{Ge}V)^{\frac{1}{2}} = 100\mathrm{Ge}V$$

Another possible critique of our argument is that it seems just to change the context of the hierarchy problem.

The particle hierarchy problem seems just to merge into a general cosmological one:

- The cosmological constant is taken to correspond to the vacuum energy density caused by a condensate. The properties of the condensate have to somehow reflect the GUT scale of the interactions when it presumably was formed.
- The flatness of the universe requires a non-vanishing, 3 meV cosmological constant. The mismatch is 10^{27}.

The commonly envisioned solution is:

- Something like supersymmetry or extra dimension is responsible for the scale separation of particle masses.
- A potential and the mass terms exactly cancel at the GUT scale condensation.
- A potential and the mass terms exactly cancel at the electro-weak symmetry breaking scale condensation.
- A potential and the mass terms almost cancel at chiral symmetry breaking scale condensation. A tiny unbalance is then responsible for the dark energy.

The implied factorization of different scales seems difficult. We here consider it to be impossible to create such scales factors in a direct dynamical way: A Lagrangian with GUT scale mass terms cannot contain minima in its effective potential involving such tiny scales.

There is a formal problem with the conventional view.
The argument is quite simple.

The term hierarchy problem is used if

- from a single available scale derived scales have to be obtained which are non-vanishing but many orders of magnitude away

The discussed cosmological problem is **not a hierarchy problem**. Other scales like the age of the universe are available which can bridge the gap.
Without hierarchy problem the mentioned drastic assumptions are not sufficiently motivated.

Cosmological Consideration

It is easy to envision an evolution in which the age of the universe bridges the gap.

The central assumption needed is just that there is no additional energy scale available in the evolution. In solid state physics such situations are well known and called gap-less.

Without additional scales the change of dark energy within a comoving cell $\epsilon_{\text{vac.}}$ has to be *something like*:

$$\partial\epsilon_{\text{vac.}}/\partial(\epsilon_{\text{vac.}}t) = -\kappa\epsilon_{\text{vac.}}$$

where κ is a dimensionless decay constant and t the time.
It leads to a simple linear decrease, i.e. $\epsilon_{vac.} = \frac{1}{\kappa \cdot t}$.

The expansion of the universe a is not linear with age.
If one wants to be more precise the time t in above equation has therefore to be replaced by the dynamical relevant expansion constant a.
This constant is between $a \sim \sqrt{t}$ and $a \sim t^{2/3}$.

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$\longrightarrow$ The ratio $\frac{\epsilon_{GUT}}{\epsilon_{Vacuum}(t_0)} = 10^{27}$ can then be obtained from the age of universe $t_0 = 5 \cdot 10^{46}/M_{GUT}$ in GUT units as

$$a \propto {t_0}^{0.5} = (5 \cdot 10^{46})^{0.5} = 2.2 \cdot 10^{23}$$

resp.

$$a \propto {t_0}^{2/3} = (5 \cdot 10^{46})^{2/3} = 1.3 \cdot 10^{31}$$

to the accuracy of the approximation.

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Without a new scale the energy density of a truly minimal vacuum condensate has to be zero.

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- The spontaneous symmetry breaking is replaced by an evolving process with its unavoidable uncertainties.

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This consideration suggests a

largely random 'Emergent' Vacuum state.

A rough history of such a vacuum condensate looks like this:

1. The condensation involves first chaoticly formed bound states. These firmly bound states are then 'massless' seen from the GUT scale. They are localized on a GUT scale.
2. These 'massless' bosonic objects can spread out in space as single bosons or within bound configurations.
   In this way they decouple from the hotter rest.
   Decoupling is here the defining property of "Vacuum".
3. Nowadays they fill the entire space. It has to be constant on a cosmic (GLyr) scale. Quantum mechanical processes have to have created a Vacuum state which is coherent at least on a flavor decay scale.

The Vacuum as Emergent Phenomena

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If you insist to have it "worked out" in detail
you did not get the defeatist point.

General Consideration to the Emergent Vacuum

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Of course one has to try to move on and try to formulate the Emergent Vacuum in a definite mathematical way. It seems somewhat heroic as there are too many open ends.

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- Quimbay and Morales assume an equilibrium and use the zero temperature limit of a **thermal field theory**
- **Volovik and Klinkhamer** try to rely on analogies to solid state physics.
- **Bjorken** tries special QED structures and argues that the situation is somewhat analogous to the time around 1960 where one had to turn to effective theories to parameterize the data. The fundamental QCD-like physics will then appear on a Planck scale.

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Here we will **not attempt to contribute to this difficult problem.**

- Our central observation is that a partially accidental Emergent Vacuum scenario requires that the textbooks of particle physics have to be rewritten.

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- One has to more careful in claiming the discovery of broken symmetries of fundamental physics. They might just reflect basically accidental asymmetric properties of the Vacuum.

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Even without detailed understanding of the emergent Vacuum there are rather unavoidable consequences. It leads on a qualitative level to meaningful **consistency checks** and **testable consequences**.

Assumption about Dark Matter and Energy

The Vacuum interacts with gravitation and, not unique, it can be compressed in the gravitational potential of galaxies.
This blurs the distinction between Dark Energy and Matter.

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Simplicity postulate:

$\Rightarrow$ Dark Matter is essentially due to compressed Dark Energy.

- With a suitable parameterization of the compressibility this can lead to a MoND-like theory with some advantages.

More slowly:
If dark matter is caused by invisible particles
it is hard to understand why there are no big fluctuations between visible and dark matter?
To solve this problem a fundamentally Modified Newtonian Dynamics ('MoND') containing an extra galactic scale gained popularity.
Adjusting the compressibility of the Emergent Vacuum (instead of changing the gravitational force) such a nonlinear theory can obviously obtain the same results in a straight forward way.
There is no fine tuning required. The averaged densities of dark matter and dark energy (and matter) are of the same one or two orders of magnitude.

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$\Rightarrow$ Only the known physics has to be explained.

Assumption about Particle-Antiparticle Symmetry

For particle physics an important property of the Vacuum is that it can act as **reservoir**. It has several consequences. We begin with the most drastic one.

The ***apparent baryonic matter antimatter asymmetry*** is one of the most ugly aspects in the present textbook. The conventional explanations are unsatisfactory.

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- It is also widely agreed that no suitable, sufficiently strong asymmetry generating process could be identified.

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- To have just the right initial condition seems awkward.
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- With the Emergent Vacuum there is a simple solution:

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- A repulsive fermionic component might be important for the stability of the condensate. Most known condensates have a repulsive fermionic component.
- The repulsive force of the essentially massless extremely extended fermions should play an important role in the cosmological expansion possibly replacing inflatons.

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- Are there problems with such a picture?

Vacuum Cherenkov radiation?

There is a firm limit for such Vacuum structures from the unobserved vacuum Cherenkov radiation.

As the baryon outside have to correspond to the antibaryon within the Vacuum the density can be estimated as

$$\begin{aligned} n_{\text{baryon}} &= \rho_c \cdot \Omega_{\text{baryon}} / m_{\text{neutron}} = \\ &= 0.25 \cdot \mathrm{m}^{-3} = 1.9 \cdot 10^{-39} \quad (\frac{\mathrm{MeV}}{\hbar c})^3 \end{aligned}$$

The bound states in the considered Vacuum have no initial dipole moments. A factor $(10^{15}\mathrm{MeV}/\hbar\mathrm{c})^{-3}$ has to be added to obtain the dielectric constant of GUT scale bound state. The result is well below $\frac{\epsilon(\mathrm{Vacuum})}{\epsilon_0} - 1 \approx \theta_C^2 < 10^{-18}$ limit from the unobserved vacuum Cherenkov radiation.

Antineutron Decay?

The simplicity postulate presumably requires grand unification. A path which includes $SU(5)$ leptoquark transitions could create a problem as antineutron decay might not be prohibited in a suitable hot state of the evolution.

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- It depends on the symmetry breaking and the way how various masses appear. So presumably there is no problem.
- If the GUT scale binding of the Vacuum constituents involves generation changing gauge bosons the left and right handed mass partner do not need to be in the same $SU(5)$ or $SO(10)$ multiplet.

  Such a mechanism would then also explain the absence of proton decay.

As it is disconnected I put it in a backup page.

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- Known condensation often involves replication processes amplifying initial asymmetries over many decades.
- Annihilation processes within the Vacuum radiating into the visible world should purify its antimatter nature.
- The condensation precedes at least part of an inflationary period. In this way a relatively small area can be magnified to extend over essentially our complete horizon.

Expected Non-Uniformities?

Two natural expectations:

- The Vacuum of the past was denser.
- There is, however, no reason that the tiny region we originate in happens to have a constant (i.e. extremal) Vacuum density.
  A geometric variation should lead to a ”Dipole” contribution.

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Practical consequence:

- The known fermion and weak vector boson masses increase with the densities

The Fine Structure Constant is not Fundamental!

The fine structure constant $\alpha \propto e^2$ is determined by the $U(1)$ and $SU(2)$ constants at M_w mass scale as

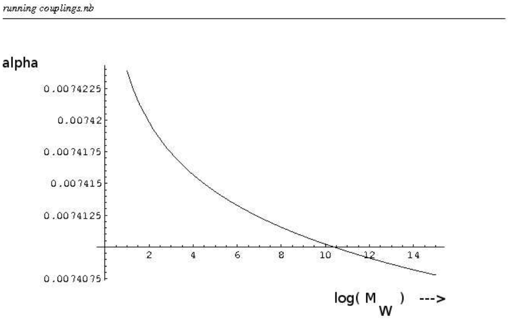
$$1/e^2 = 1/g^2 + 1/g'^2 = 1/g_2^2 + \frac{5}{3}/g_1^2$$

As $1/e^2$ runs more than $1/g^2 + 1/g'^2$ it depends on this M_w which is not fundamental in our scheme.

Actually the electric neutrality of the Vacuum plays an important role. It fixes the weak angle and it has the consequence that the Gell-Mann-Nishijima relation holds independent of M_w.

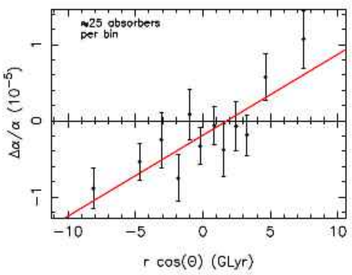
For a denser Vacuum and a larger M_W the steeper rise on the left side (of the running $1/e^2$ and not $1/g^2 + 1/g'^2$) increases the final $1/e^2$.

For the fine structure constant it looks like this:



A spatial variation ("Australian Vector") was observed by Webb et co-workers.

$$\Delta\alpha/\alpha \sim B\cos(\Theta) + m$$



Its existence follows expectation.
It fixes the scale of the uniformity to $B = 1.1 \pm 0.8 \cdot 10^{-6}\,\mathrm{GLyr}^{-1}$.

The offset $m = -1.9 \pm 0.8 \cdot 10^{-6}$ just looks in the denser past.
Its negative sign confirms the expected increase in $1/e^2$.
The negative sign is also indicated by the LNE-SYRTE clock assemble yielding:

$$\frac{\partial}{\partial t}\alpha/\alpha = -0.18 \pm 0.23\;(10^{16}\mathrm{year})^{-1}$$

How do masses arise?

- All mass-matrix elements of mass terms have to originate in interactions with the Vacuum.
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- The various mass values have to reflect Vacuum densities.

The **number of mass parameters** is generally considered to be **excessive.** Here it is attributed **to the emergent Vacuum**.
They are no longer part of fundamental physics.

Effective Lorentz Invariance

The spatial extension of Vacuum state requires vanishing momentum transfers by scalar interactions of a low energy effective theory.

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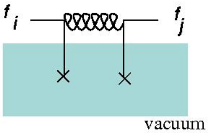
The spatial extension of Vacuum state requires vanishing momentum transfers by scalar interactions of a low energy effective theory.

- In consequence the Lorentz system of the very light Vacuum state can then not be seen.
  Lorentz invariance holds in the outside world separately.

About the Fermion Mass Matrix

In the lowest perturbative order an interaction with the Vacuum has a contribution connecting to a specific corresponding flavor:

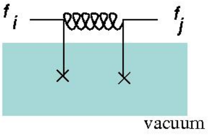


Relying on a Fierz transformation,
it contains a scalar term needed in the low momentum limit.

Such fermion-exchange contributions between the visible world and the Vacuum should keep their symmetry structure and remain dominant when higher orders are included.

The Vacuum as zero temperature limit of a thermal field theory of Quimbay and Morales leads to very similar results.

Both fermions do not have to be identical. As the Vacuum has to stay neutral the matrix decomposes into 4 separate 3×3 matrices. They can be diagonalized and the **CKM matrix can be obtained in the usual way**.



Flavor changing neutral currents could arise if there is a scale dependence in the diagonalization of these matrices. As in the standard model the exchange of weak vector bosons will introduce a tiny scale dependence many orders below a possible observation. The contribution of possible even heavier new bosons (discussed below) will be even tinier.

About the Flavor Conservation

As both flavor do not have to be identical ***flavor conservation is restored*** and
the apparent flavor changes in the outside world is attributed to a **reservoir effect** of the Vacuum.

To be clear p.e. the so-called strangeness decay just means that a d-quark in the Vacuum is just replaced by an s-quark.

Symmetries

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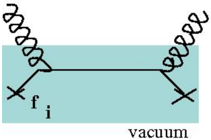
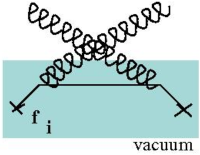
- However, a $(\bar{q}_i)_V/(q_i)_V$ asymmetry in the Vacuum will differentiate between $q_i + (\bar{q}_i)_V \rightarrow q_j + (\bar{q}_j)_V$ and $\bar{q}_i + (q_i)_V \rightarrow \bar{q}_j + (q_j)_V$. In consequence: ***CP is not conserved separately*** in the outside world.

About Vector Boson Masses

The vector boson mass arises to lowest order from Compton scattering graphs.





Compton scattering measures the squared charges of Vacuum content.

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  The (B, W_0) mass matrix can then be **diagonalized in the usual way**.
  $m_\gamma = 0$ is the lowest eigenvalue. It value follows from the electric neutrality of the vacuum.

Resumee

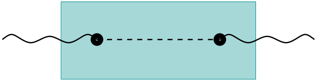
The consistencies discussed above have to be considered as

a success of the concept

.

Will there be new scalar particles at LHC?

'Vacuum' fluctuations in condensate densities are needed for the **third component of the weak vector bosons.**
The mass producing interaction can be described as an effective scalar interaction:



The effective scalar has somehow also to reflect the tumbled down Vacuum scale like the Goldstone boson mentioned above. It is also an excitation of the Vacuum and not an independent GUT scale bound state.

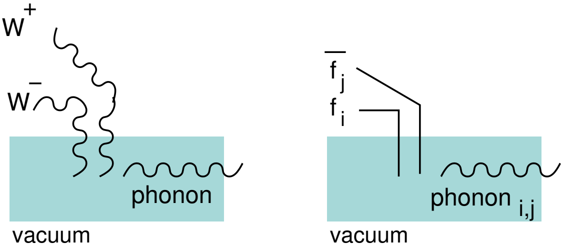
Expected Coupling

Such phononic excitations can be built with arbitrary $f_i\bar{f}_j$ -pairs and there should be plenty of such states presumably within an order of magnitude of the Weak Boson mass.

They interact with fermions in a distinct way:

They are so called **'private Higgs' particles** , which couple exactly to one fermion pair.

Their couplings to *Weak boson and fermion pairs* are:



For $q^2_{\text{phonon}} \to 0$ its interaction might corresponds to the mass term which reflects the corresponding fermion density in the Vacuum.

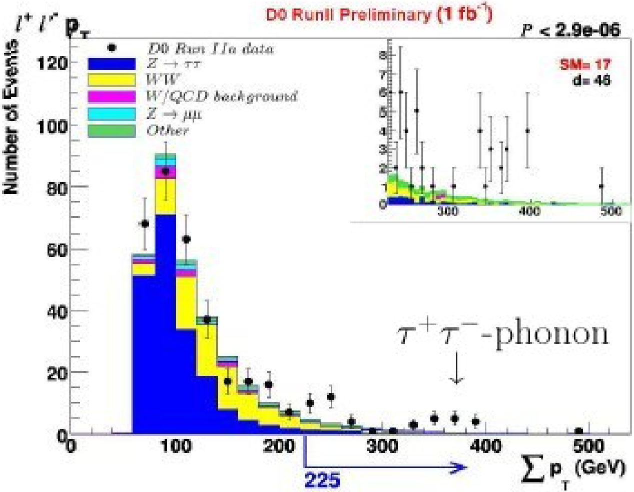
The phonon mass itself should also increase with the fermion masses.

In this way the coupling might prevent the observation of the very light phonons while the heavier phonons might be out of reach kinematically.

A suitable candidate might be the $\tau^+\tau^-$-phonon somehow observable as broad ($e^\pm\mu^\mp$ missing $p_\perp$)-structure.

An indication for such a state exists in prelimary D0 data.

Preliminary Support?



It is statistically on 'discovery' level.
At the moment they do not trust their μ-energy calibration sufficiently to announce it as such.

Conclusion

- It is not a beautifull scenario. If correct we can forget the dream about reaching the *'Theory of Everything'*. Very little was really calculated.
- However it is not unpersuasive and things fit together in a surprising way on a qualitative level.
- Private Higgs at LHC might strongly indicate that an Emergent Vacuum was *nature's choice*.

Conclusion

- It is not a beautifull scenario. If correct we can forget the dream about reaching the *'Theory of Everything'*. Very little was really calculated.
- However it is not unpersuasive and things fit together in a surprising way on a qualitative level.
- Private Higgs at LHC might strongly indicate that an Emergent Vacuum was *nature's choice*.

$\longrightarrow$ So remember this talk if they should appear.

Backup Protondecay

We take $SO(10) \times SO(3)$ where the symmetry breaking is assumed to involve $SU(5)$ and where the generational $SO(3)$ contains by some mechanism only color tripletts for fermion and gauge bosons. Fermistatiscs requires identical spin and isospin symmetry. For the antineutron decay two $\bar{d}_L$ have to decay in a q_R and a Lepton. As the right handed mass partner of the $\bar{d}_L$ quarks will be in a different SO(10 generation the produced quark will have a second generation mass.

Decays involving neutrinos are therefore kinematically not possible. Decays involving charged leptons and a strangs quark could be possible. However they might have to involve heavy leptons as the correspondin Cabibbo-Kobayashi-Maskawa matrix is unknown. Usually one doesn't like accidental zero entries. Here, however, the evolution will select stable vacuum and adjust the corresponding mass values.
So the evolution might be a reason for the missing proton decay.

RELATIONS TO OTHER WORK: (just flushed)

1. In multi-verse scenarios the truly minimal vacuum is also a random choice.
   Here the randomness is different and more natural. It is quite common that condensates adjust in a largely random way.
2. In 'age-graphic' models of the dark energy (Neupane) also changes with time.
3. Klinkhamer and Volovik treat the vacuum also as solid-state-like condensate to obtain a solution of the cosmological constant problem in general relativity. The general idea is close to our particle physics concept.
4. Quimbay and Morales take the Vacuum as zero temperature limit of a medium in a high temperature field theory. Again it is close to our concept.