USC-06/HEP-B3 [1]

hep-th/0610187

# The Standard Model as a 2T-physics Theory

Itzhak Bars

*Department of Physics and Astronomy*
*University of Southern California, Los Angeles, CA 90089-0484, USA*



**Abstract.** New developments in 2T-physics, that connect 2T-physics field theory directly to the real world, are reported in this talk. An action is proposed in field theory in 4+2 dimensions which correctly reproduces the Standard Model (SM) in 3+1 dimensions (and no junk). Everything that is known to work in the SM still works in the emergent 3+1 theory, but some of the problems of the SM get resolved. The resolution is due to new restrictions on interactions inherited from 4+2 dimensions that lead to some interesting physics and new points of view not discussed before in 3+1 dimensions. In particular the strong CP violation problem is resolved without an axion, and the electro-weak symmetry breakdown that generates masses requires the participation of the dilaton, thus relating the electro-weak phase transition to other phase transitions (such as evolution of the universe, vacuum selection in string theory, etc.) that also require the participation of the dilaton. The underlying principle of 2T-physics is the local symmetry Sp(2,R) under which position and momentum become indistinguishable at any instant. This principle inevitably leads to deep consequences, one of which is the two-time structure of spacetime in which ordinary 1-time spacetime is embedded. The proposed action for the Standard Model in 4+2 dimensions follows from new gauge symmetries in field theory related to the fundamental principles of Sp(2,R). These gauge symmetries thin out the degrees of freedom from 4+2 to 3+1 dimensions without any Kaluza-Klein modes. The extra 1+1 dimensions are compensated by the Sp(2,R) gauge symmetry that removes ghosts and cure other problems such as causality. The SM emerges from 4+2 dimensions as one of the gauge choices in coming down from 4+2 to 3+1 dimensions. As is usual in 2T-physics, there are many ways of embedding 3+1 in 4+2 as gauge choices, and this should lead to holographic images that appear as different 1T-dynamics, but are dual field theories of the SM. This is likely to lead to new methods for investigating QCD and other field theories. The dualities among the 3+1 dimensional images, and the hidden symmetries of 4+2 dimensions realized by each image, is part of the evidence for the underlying 4+2 dimensions.

## 1. SP$(2,R)$ GAUGE SYMMETRY AND 2T-PHYSICS

The essential ingredient in 2T-physics is the basic gauge symmetry Sp$(2,R)$ acting on phase space $X^M, P_M$ [1]. Under this gauge symmetry, momentum and position are locally indistinguishable, so the symmetry leads to some deep consequences [1] - [13]. One of the strikingly surprising aspects of 2T-physics is that a given $d+2$ dimensional 2T theory descends, through Sp$(2,R)$ gauge fixing, down to a family of holographic 1T

---

[1] Lectures delivered at SUSY06, the 14th International Conference on Supersymmetry and the Unification of Fundamental Interactions, Irvine, CA, June 2006, and at the $26^{th}$ International Colloquium on Group Theoretical Methods in Physics, New York, NY, June 2006. Transparencies available at http://physics.usc.edu/~bars/papers/2TSMlecture.pdf.

images in (d-1)+1 dimensions, all of which are gauge equivalent to the parent 2T theory and to each other. However, from the point of view of 1T-physics each image appears as a different dynamical system with a different Hamiltonian. Some of the phenomena that emerge in 2T-physics include certain types of dualities, holography and emergent spacetimes, which have been studied primarily at the level of classical and quantum particle dynamics (Fig.1).

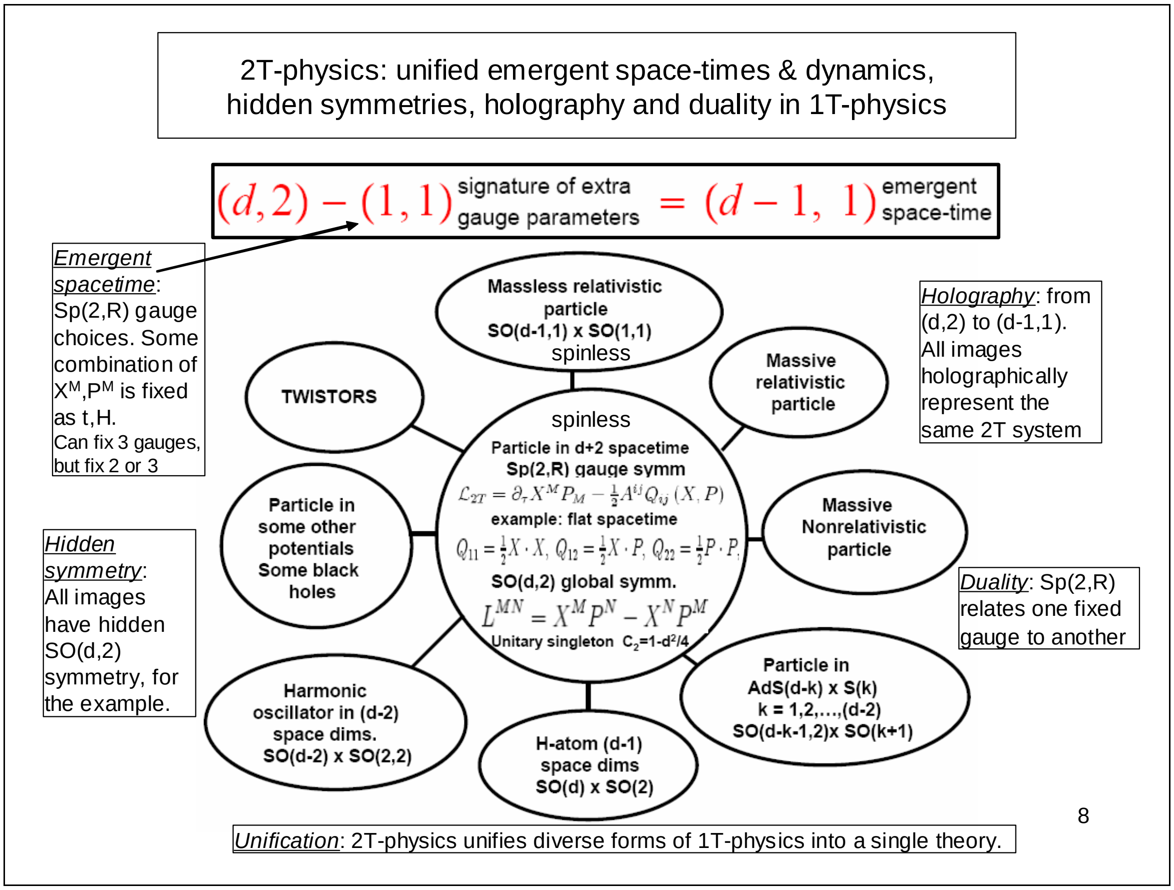

Fig.1 - Some 1T-physics systems that emerge from the solutions of $Q_{ij} = 0$.

Hence, 2T-physics is a unification approach for 1T-physics systems through higher dimensions. It is distinctly different than Kaluza-Klein theory because there are no Kaluza-Klein towers of states, but instead there is a family of 1T systems with duality type relationships among them.

In the field theoretic 4+2 SM the type of phenomena summarized in Fig.1 are expected. For the time being only one of the field theoretic images, namely the one labeled as “massless relativistic particle” in Fig.1, has been studied. It is this 3+1 holographic image of the 4+2 SM that coincides with the well known 3+1 SM. This emergent SM has some attractive features: it solves the long standing CP problem, and leads to novel ideas on the origins of mass generation, as mentioned in the abstract.

I now describe the main features of the 2T-physics field theory and its consequences in $4+2$ dimensions. The generic field theory with fields of spins $0, 1/2$, and 1 includes a set of SO$(4,2)$ vectors $A_M^a(X)$ labeled with $M =$ SO$(4,2)$ vector, and $a =$ the adjoint representation of some Yang-Mills gauge group $G$; scalars $H_i(X)$, labeled by an internal symmetry index $i=1,2,\cdots$ (a collection of irreducible representations of $G$); left or right handed spinors $\Psi^I_{L\alpha}(X), \Psi^{\tilde{I}}_{R\dot{\alpha}}(X)$ in the $4,4^*$ representations of $\mathrm{SU}(2,2)=\mathrm{SO}(4,2)$, labeled with $\alpha=1,2,3,4$, and $\dot{\alpha}=1,2,3,4$, and internal symmetry indices $I=1,2,\cdots$ and $\tilde{I}=1,2,\cdots$ (again, a collection of irreducible representations of $G$). The generic Lagrangian has the form of a Yang-Mills theory in $4+2$ dimensions ($G$-covariant derivatives), except for space-time features shown explicitly in the Lagrangian below, needed to impose the underlying $\mathrm{Sp}(2,R)$ gauge symmetry and the related 2T-physics gauge symmetries.

There is no space here to give the details of the 2T-physics gauge symmetries in field theory [11, 12], but I note the basic important fact that the equations of motion that follow from the Lagrangian below impose the $\mathrm{Sp}(2,R)$ gauge singlet conditions $X^2 = X\cdot P = P^2 = 0$ indicated in Fig.1, but now including interactions [12]

$$
\begin{aligned}
L = &\ \delta\left(X^2\right)\left\{-D_M H^{i\dagger} D^M H_i\right\} + 2\ \delta'\left(X^2\right)\ H^{i\dagger} H_i \\
&+ \delta\left(X^2\right)\left\{\begin{array}{c} \frac{i}{2}\left(\overline{\Psi_L}^I X\bar{D}\Psi_{IL} + \overline{\Psi_L}^I \overleftarrow{\bar{D}}\bar{X}\Psi_{IL}\right) \\ -\frac{i}{2}\left(\overline{\Psi_R}^{\tilde{I}}\bar{X}D\Psi_{\tilde{I}R} + \overline{\psi_R}^{\tilde{I}}\overleftarrow{\bar{D}}X\Psi_{\tilde{I}R}\right)\end{array}\right\} \\
&+ \delta\left(X^2\right)\left\{g_I^{i\tilde{I}}\overline{\Psi_L}^I X\Psi_{\tilde{I}R}H_i + \left(g_I^{i\tilde{I}}\right)^* H^{*i}\overline{\Psi_R}^{\tilde{I}}\bar{X}\Psi_{IL}\right\} \\
&+ \delta\left(X^2\right)\left\{-\frac{1}{4}F^a_{MN}F_a^{MN} - V\left(H,H^*,\Phi\right)\right\} \\
&- \frac{1}{2}\delta\left(X^2\right)\ \partial_M\Phi\partial^M\Phi + \delta'\left(X^2\right)\ \Phi^2
\end{aligned}
$$

The distinctive space-time features in 4+2 dimensions include the delta function $\delta\left(X^2\right)$ and its derivative $\delta'\left(X^2\right)$ that impose $X^2 = X^M X_M = 0$, the kinetic terms of fermions that include the factors $X\bar{D}, \bar{X}D$, and Yukawa couplings that include the factors $X$ or $\bar{X}$, where $X \equiv \Gamma^M X_M$, $\bar{D} = \bar{\Gamma}^M D_M$ etc., with $4\times 4$ gamma matrices $\Gamma^M, \bar{\Gamma}^M$ in the $4,4^*$ spinor bases of $\mathrm{SU}(2,2)$=$\mathrm{SO}(4,2)$. This Lagrangian is not invariant under translation of $X^M$, but is invariant under the spacetime rotations $\mathrm{SO}(4,2)$.

This Lagrangian has precisely the right space-time, and gauge invariance, properties for the $4+2$ field theory to yield the usual $3+1$ field theory via gauge fixing, with the usual kinetic terms and Yukawa couplings in the emergent $3+1$ dimensional Minkowski space $x^\mu$. The emergent $3+1$ theory contains just the right fields as functions of $x^\mu$: all extra degrees of freedom disappear without leaving behind any Kaluza-Klein type modes or extra components of the vector and spinor fields in the extra 1+1 dimensions. Furthermore, the emergent $3+1$ field theory is invariant under translations and Lorentz transformations $\mathrm{SO}(3,1)$: these Poincaré symmetries are included in $\mathrm{SO}(4,2)$ that takes the non-linear form of conformal transformations in the emergent $3+1$ dimensional space-time $x^\mu$, as indicated in Fig.1.

As in the last line of the Lagrangian, one may also include an additional $\mathrm{SO}(4,2)$ scalar, the dilaton $\Phi(X)$, classified as a singlet under the group $G$. The dilaton is not optional if the action is written in $d+2$ dimensions (see [12]), as it appears in overall factors $\Phi^{\frac{2(d-4)}{d-2}}, \Phi^{-\frac{d-4}{d-2}}$ multiplying the Yang-Mills kinetic term and Yukawa terms respectively, in order to achieve the 2T-gauge symmetry of the action. In $4+2$ dimensions ($d=4$) these factors reduce to 1, but the dilaton can still couple to the scalars $H$ in the potential $V(H, H^*, \Phi)$.

While almost all of the usual terms of $3+1$ dimensional Yang-Mills theory coupled to matter appear in the $3+1$ theory that emerges from the $4+2$ field theory above, there are two notable exceptions that play an important and interesting physical role when we apply the $4+2$ approach to construct the Standard Model. Namely,

- The 2T-gauge symmetry requires the potential $V(H, H^*, \Phi)$ to be purely quartic, i.e. no mass terms are permitted. Then the emergent 3+1 theory cannot have mass terms for the scalars, and is automatically invariant under scale transformations.
- There is no way to generate a term in the emergent $3+1$ theory that is analogous to the P and CP-violating $F_{\mu\nu}F_{\lambda\sigma}\varepsilon^{\mu\nu\lambda\sigma}$ term that is possible in $3+1$ dimensions. Its absence[2] is due to the fact that the Levi-Civita symbol in $4+2$ dimensions has 6 indices rather than 4, and also due to the combination of 2T gauge symmetry as well as Yang-Mills gauge symmetry. The absence of this CP-violating term is of crucial importance in the axionless resolution of the strong CP violation problem of QCD suggested in [12].

The 2T-physics field theory above is applied to construct the Standard Model in 4+2 dimensions by choosing the gauge group $G=$SU$(3)\times$SU$(2)\times$U$(1)$ and including the usual matter representations for the Higgs, quarks and leptons (including right handed neutrinos in singlets of $G$), but now as fields in $4+2$ dimensions. As explained in [12] this theory descends to the usual Standard Model in $3+1$ dimensions.

The emergent $3+1$ theory leads to phenomenological consequences of considerable significance. In particular, the higher structure in $4+2$ dimensions prevents the problematic $F*F$ term in QCD. This resolves the strong CP problem without a need for the Peccei-Quinn symmetry or the corresponding elusive axion.

Mass generation with the Higgs mechanism is less straightforward since the tachyonic mass term is not allowed. However by taking the potential of the form $V(\Phi, H) = \frac{\lambda}{4}\left(H^\dagger H - \alpha^2\Phi^2\right)^2$ we obtain the breaking of the electroweak symmetry by the Higgs doublet $\langle H\rangle$ driven by the vacuum expectation value of the dilaton $\langle\Phi\rangle$, thus relating the the two phase transitions to each other. In this way the 4+2 formulation of the Standard Model provides an appealing deeper physical basis for mass. In addition, there are some brand new mechanisms of mass generation related to the higher dimensions that deserve

---

[2] In searching for possible 4+2 sources that may generate the CP violating term in 3+1, one must include the requirement that the $4+2$ theory should not include terms that descend to non-normalizable interactions in $3+1$. Actually there appears as if there would be a topological term of the form $\int d^6X\ \varepsilon^{M_1M_2M_3M_4M_5M_6}Tr\left(F_{M_1M_2}F_{M_3M_4}F_{M_5M_6}\right)$ whose density is a total divergence for any Yang-Mills gauge group $G$, and therefore should not affect the equations of motion, or renormalizability. However, as discussed in [12], this term can be gauge fixed to zero by using the 2T gauge symmetry. In this sense, the 2T gauge symmetry plays a similar role to the Peccei-Quinn symmetry in eliminating the topological term. But one must realize that the 2T gauge symmetry is introduced for other more fundamental reasons and also it is not a global symmetry. Hence, unlike the Peccei-Quinn symmetry it does not lead to an axion.

further study (e.g. massive particle gauge in Fig.1).

The dilaton driven electroweak phase transition makes a lot more sense conceptually than the usual approach in which the electroweak phase transition is an isolated phenomenon. This is because the Higgs vacuum expectation value fills all space everywhere in the universe. This is a hard concept to swallow without relating it to the evolution of the universe, which then requires the participation of gravity. By having $\langle H\rangle$ being driven by the dilaton, not only the relation to the behavior of the gravity multiplet is established, but also a relation is established to other phase transitions, such as the vacuum selection process in string theory (which depends on the dilaton), and perhaps even to inflation that is driven by a scalar field which could be the dilaton.

Although unclear at the present for lack of a full understanding of the quantum theory, we may have also found the seeds for a resolution of the hierarchy problem in 2T-physics. Namely, the absence of quadratic terms is a consequence of symmetry at the classical level, and if the symmetry is not anomalous it would lead to the absence of the quadratic divergence at the quantum level, thus resolving the hierarchy problem.[3]

The 4+2 formulation requires the kinds of concepts above that are not required and therefore not contemplated in the literature of the usual Standard Model or its extensions in $3+1$ dimensions.

The presence of the dilaton, as well as the right handed neutrinos, are features with further phenomenological consequences. Both of these are very weakly coupled to standard matter. Hence they are possible candidates for Dark Matter. In particular, the dilaton communicates with all other matter only through the Higgs. If a Higgs is found at the LHC, it could provide a gateway to measure phenomenological effects of the required dilatonic degree of freedom in the 4+2 formulation of the Standard Model.

In summary, I emphasize the following physics points that the new formulation of the Standard Model implies

- 2T-physics works and is a physical theory! Local $\mathrm{Sp}(2,R)$ (i.e. $X,P$ indistinguishable) is a fundamental principle that agrees with everything we know about Nature as embodied by the Standard Model.
- The Standard Model in 4+2 dimensions provides new guidance to fundamental physics: it resolves the strong CP violation problem of QCD, and leads to the appealing concept of dilaton driven electroweak spontaneous symmetry breakdown.
- A weakly coupled dilaton may have phenomenological signals at the LHC. It could also be a candidate for Dark Matter. Since this is a required particle in the 4+2 formulation, and since this formulation solves the fundamental CP problem, the dilaton concept and its possible observation at the LHC must be taken seriously.
- The 2T-physics concepts are easily applied to physics Beyond the Standard Model, including GUTS, SUSY, and gravity. All of these can be elevated to 2T-physics in d+2 dimensions. These will be reported in the near future.
- Strings and branes have only been partially formulated in 2T-physics. In particular, tensionless strings and branes, and the twistor superstring, have already been obtained.

---

[3] I thank C. Johnson for drawing my attention to this point.

- Similarly, it is expected that 2T-physics is a good guide for constructing M-theory in 11+2 dimensions with an $\mathrm{OSp}(1|64)$ global SUSY.
- There seems to be practical advantages of formulating 1T physics from the vantage point of d+2 dimensions. This is seen by examining the type of phenomena summarized in Fig.1. Namely, 2T-physics provides new insights: emergent spacetimes and dynamics, unification, holography, duality, hidden symmetries, that could be used to analyze theories such as QCD and others in a non-perturbative fashion. I hope that this aspect of 2T-physics will become an effective tool in the future.

## ACKNOWLEDGMENTS

I gratefully acknowledge discussions with S-H. Chen, Y.C. Kuo, B. Orcal, and G. Quelin. This research was supported by the US Department of Energy, under Grant No. DE-FG03-84ER40168

## REFERENCES

1. I. Bars, C. Deliduman and O. Andreev, “ Gauged Duality, Conformal Symmetry and Spacetime with Two Times" , Phys. Rev. **D58** (1998) 066004 [arXiv:hep-th/9803188]. For reviews of subsequent work see: I. Bars, “ Two-Time Physics" , in the Proc. of the 22nd Intl. Colloq. on Group Theoretical Methods in Physics, Eds. S. Corney at. al., World Scientific 1999, [arXiv:hep-th/9809034]; “ Survey of two-time physics," Class. Quant. Grav. **18**, 3113 (2001) [arXiv:hep-th/0008164]; “ 2T-physics 2001," AIP Conf. Proc. **589** (2001), pp.18-30; AIP Conf. Proc. **607** (2001), pp.17-29 [arXiv:hep-th/0106021]. “Lectures on twistors,” arXiv:hep-th/0601091.
2. I. Bars and C. Deliduman, Phys. Rev. **D58** (1998) 106004, hep-th/9806085.
3. I. Bars, “Two time physics with gravitational and gauge field backgrounds", Phys. Rev. **D62**, 085015 (2000) [arXiv:hep-th/0002140]; I. Bars and C. Deliduman, “ High spin gauge fields and two time physics", Phys. Rev. **D64**, 045004 (2001) [arXiv:hep-th/0103042].
4. I. Bars, C. Deliduman and D. Minic, “Supersymmetric Two-Time Physics”, Phys. Rev. **D59** (1999) 125004, [arXiv:hep-th/9812161]; “Lifting M-theory to Two-Time Physics”, Phys. Lett. **B457** (1999) 275, [arXiv:hep-th/9904063].
5. I. Bars, “ 2T physics formulation of superconformal dynamics relating to twistors and supertwistors," Phys. Lett. B **483**, 248 (2000) [arXiv:hep-th/0004090]. “Twistors and 2T-physics,” AIP Conf. Proc. **767** (2005) 3 , [arXiv:hep-th/0502065].
6. I. Bars, “Twistor superstring in 2T-physics,” Phys. Rev. **D70** (2004) 104022, [arXiv:hep-th/0407239].
7. I. Bars, Lectures on Twistors, arXiv:hep-th/0601091.
8. I. Bars, “Conformal symmetry and duality between free particle, H-atom and harmonic oscillator", Phys. Rev. **D58** (1998) 066006 [arXiv:hep-th/9804028]; “Hidden Symmetries, $\mathrm{AdS}_d \times S^n$, and the lifting of one-time physics to two-time physics", Phys. Rev. **D59** (1999) 045019 [arXiv:hep-th/9810025].
9. I. Bars and M. Picon, “Single twistor description of massless, massive, AdS, and other interacting particles,” Phys. Rev. **D73** (2006) 064002 [arXiv:hep-th/0512091]; “Twistor Transform in d Dimensions and a Unifying Role for Twistors,” Phys. Rev. **D73** (2006) 064033, [arXiv:hep-th/0512348].
10. I. Bars, “ Two-time physics in Field Theory" , Phys. Rev. D **62**, 046007 (2000), [arXiv:hep-th/0003100];
11. I. Bars and Y-C. Kuo, “Interacting two-time Physics Field Theory with a BRST gauge Invariant Action”, hep-th/0605267.
12. I. Bars, “The standard model of particles and forces in the framework of 2T-physics”, hep-th/0606045.

13. P.A.M Dirac, Ann. Math. 37 (1936) 429.