Title: Phase Space Gauge Principles and Universal Consequences for Physics and Space-Time

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Abstract: Hints for the possibility of two times emerged in M-theory in 1995. If taken seriously this required new concepts that could solve unitarity (ghost) and causality problems so that physics could be described sensibly in a spacetime with two times. The necessary concept turned out to be a gauge symmetry in phase space. This is an unfamiliar concept, but is one that extends Einstein's approach to the formulation of fundamental equations of physics, by removing the perspective of the observer, not only in position space but more generally in phase space.
This approach led in 1998 to what is now called 2T-physics, which has been formulated so far in classical and quantum mechanics, field theory and partially in string theory. In this lecture I will explain the fundamental aspects of 2T-physics, and will outline the progress from classical mechanics, through the standard model and gravity, all the way to supergravity in d-space plus 2-time dimensions. I will describe how 2T-physics is consistent with 1T-physics in (d-1)-space plus 1-time dimensions, but also how it goes beyond 1T-physics, by making in principle a vast number of verifiable predictions that are systematically missed in 1T-physics, as well as providing new computational tools for physics.

Phase Space Gauge Principles and Universal Consequences for Physics and Space-Time

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January 18, 2011
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- It works for all classical & quantum mechanics, field theory the Standard Model, gravity, all the way to supergravity. String theory is still underdeveloped in this framework.
- Makes in principle a vast number of verifiable predictions that are missed systematically in the 1T formulation of physics at all scales of distance or energy.

Strong hints for 2T-physics came from M-theory (IB -1995):
Extended SUSY of 11D M-theory is really a SUSY in 12 dimensions

$$\{Q_{32},Q_{32}\}=(P+Z_{[2]}+Z_{[5]})_{11D}=(T_{[2]}+T_{[6]+})_{12D}$$

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If 2 times are taken seriously there are huge problems,
how does one remove the ghosts and causality problems?

Kaluza-Klein is the wrong idea for extra time dimensions:

e.g. $A_M(X^M)$ has wrong sign kinetic terms,

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and the extra time dimensions from X^M.

e.g. $A_M(X^M) \rightarrow A_\mu(x^\mu)$, etc

What remains?

1T shadows! **with many kinds of <u>1T spaces</u>**

2T-physics developed by finding the <u>fundamental solution to the</u> **ghost problem** & related **causality problem**.

The answer (1998) is a <u>gauge symmetry in phase space X^M, P_M</u>

This is independent of M-theory, but I think will eventually explain (M-)S-theory, with OSp(1|64) SUSY

Like all gauge symmetries, also introduces a new universal principle for constructing the **dynamics**.

It is compatible with 1T-physics for all known phenomena, furthermore goes beyond 1T-physics in revealing additional hidden information.

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- **Canonical transformations turned into gauge symmetry.** Start with worldline, then field theory, then ... (not a completed project, but expect ultimately field theory in phase space)
- **2T is not an input**, it is a consequence of gauge symmetry.

Classical and quantum phase space

- Shadows and 1T surprises
- Background fields
- Spin
- SUSY
- Twistors
- Strings & Branes (partially)

Local Field Theory

- BRST field theory approach
- 2T Standard Model in 4+2
- 2T Gravity in d+2
- 2T SUGRA in 4+2
- N=1,2,4 SUSY field theory in 4+2
- SYM in 10+2 (→Matrix theory)
- M-theory limit as 11+2 sugra (project)
- Cosmology – Big Bang + Inflation
- Phenomenology: LHC, other
- New computational methods in d+2 using the shadows (Weinberg)

Phase space field theory

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- Derived phase space Sp(2,R) eqs from variation principle in NC field theory
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The same principle for all physics: Sp(2.R) gauge symmetry in phase space, and appropriate extensions with spin and SUSY

Phase space symmetry in particle classical mechanics

$$L = \partial_\tau X^M P_M - \cdots$$

A huge symmetry of the first term in L under GLOBAL canonical transformations.

$$\delta X^M = \frac{\partial \varepsilon(X,P)}{\partial P_M} = \{X^M, \varepsilon\},$$

$$\delta P_M = -\frac{\partial \varepsilon(X,P)}{\partial X^M} = \{P_M, \varepsilon\}$$

$$\delta_\varepsilon \{X^M, P_N\} = 0 \qquad \delta_\varepsilon [X^M, P_N] = 0.$$

$$\delta\left(\partial_\tau X^M P_M\right) = \partial_\tau\left(P_M \frac{\partial \varepsilon(X,P)}{\partial P_M} - \varepsilon(X,P)\right)$$

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These ε(X,P) contain all gauge transformations Maxwell, Einstein, Yang-Mills, & MUCH MORE ...

$$L = \partial_\tau X^M P_M - H(X,P)$$
$$\delta_\varepsilon H = \{H, \varepsilon\}$$

$$\varepsilon(X,P) = \Lambda(X) + \varepsilon^M(X) P_M + \varepsilon^{MN}(X) P_M P_N + \cdots$$
$$H(X,P) = G^{MN}(X)(P_M + A_M(X))(P_N + A_N(X)) + \cdots$$

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Proposal (1998): To be able to remove ghost degrees of freedom from X,P, promote canonical transformations to a gauge symmetry by localizing on the worldline (every instant of motion)

$$\varepsilon(X(\tau), P(\tau), \tau)$$

Gauge Symmetry in Phase Space

$$\varepsilon(X(\tau), P(\tau), \tau) = \sum_a \varepsilon^a(\tau) Q_a(X, P) \qquad \{Q_a, Q_b\} = f_{ab}{}^{c} Q_c$$

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$$\boxed{\left\{H,Q_a\right\} = 0} \qquad \delta L \;=\; \partial_\tau\left(P_M\frac{\partial\varepsilon\left(X,P,\tau\right)}{\partial P_M} - \varepsilon\left(X,P,\tau\right)\right)$$

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Equation of motion $Q_a(X,P)=0$ means only gauge invariant subspace of phase space is physical.

Analogous to Virasoro constraints in string theory.

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Familiar example: relativistic particle

$$L = \dot{x}^\mu p_\mu - e(\tau)\frac{p^2}{2}$$

More general, any Q(X,P) : 1-parameter **non-compact** Abelian gauge symmetry. **Requires 1T** and removes ghosts from 1T phase space

Sp(2,R) gauge symmetry

Three generators $Q_{ij}(X,P)$: $\{Q_{11}, Q_{22}, Q_{12}=Q_{21}\}$ form Sp(2,R) under Poisson brackets.

$A^{ij}(\tau)$ is the Sp(2,R) gauge potential, i=1,2 is label for Sp(2,R) doublet.

$$\mathcal{L}_{2T} = \partial_\tau X^M P_M - \frac{1}{2} A^{ij} Q_{ij}(X,P) \quad -H(X,P)$$

Example, flat spacetime:

$Q_{11}=X.X$, $Q_{22}=P.P$, $Q_{12}=X.P$, any signature metric → doublet $(X,P)_i$

General $Q_{ij}(X,P)$ – expand in powers of P_M, coefficients= fields

c.t. generate general coordinate symmetry, gauge symmetry, and much more symmetry (hep-th/0103042).

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In flat case
Global symmetry SO(d,2)
$L^{MN}=X^M P^N - X^N P^M$, $\{Q_{ij}, L^{MN}\}=0$.
So L^{MN} is gauge invariant.
Could add $H(L^{MN})$, could break SO(d,2) is OK, still gauge inv.

$X \cdot X = X \cdot P = P \cdot P = 0$ $\quad ds^2 = dX^M dX^N \eta_{MN} = -2dX^{+'} dX^{-'} + dX^\mu dX^\nu \eta_{\mu\nu} \quad X^{\pm'} = \frac{1}{\sqrt{2}}\left(X^{0'} \pm X^{1'}\right)$

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$X^{+'}(\tau)$	$X^{-'}(\tau)$	$X^{\mu}(\tau)$
$P^{+'}(\tau)$	$P^{-'}(\tau)$	$P^{\mu}(\tau)$

Make 2 gauge choices. Solve 2 constraints. Remains 1 gauge choice and 1 constraint

$X \cdot X = X \cdot P = P \cdot P = 0$ $ds^2 = dX^M dX^N \eta_{MN} = -2dX^{+'} dX^{-'} + dX^\mu dX^\nu \eta_{\mu\nu}$ $X^{\pm'} = \frac{1}{\sqrt{2}}\left(X^{0'} \pm X^{1'}\right)$

Relativistic massless particle	$X^M =$	1 $X^{+'}(\tau)$	$\frac{1}{2}x^2$ $X^{-'}(\tau)$	x^μ $X^\mu(\tau)$
$p^2 = 0$	$P^M =$	0 $P^{+'}(\tau)$	$x \cdot p$ $P^{-'}(\tau)$	p^μ $P^\mu(\tau)$

Make 2 gauge choices. Solve 2 constraints. Remains 1 gauge choice and 1 constraint

$X\cdot X = X\cdot P = P\cdot P = 0$ $\quad ds^2 = dX^M dX^N \eta_{MN} = -2dX^{+'}dX^{-'} + dX^\mu dX^\nu \eta_{\mu\nu}$ $\quad X^{\pm'} = \frac{1}{\sqrt{2}}\left(X^{0'} \pm X^{1'}\right)$

		$X^{+'}(\tau)$ / $P^{+'}(\tau)$	$X^{-'}(\tau)$ / $P^{-'}(\tau)$	$X^{\mu}(\tau)$ / $P^{\mu}(\tau)$
Relativistic massless particle	$X^M =$	1	$\frac{1}{2}x^2$	x^μ
$p^2 = 0$	$P^M =$	0	$x\cdot p$	p^μ
Relativistic massive particle	$X^M =$	$\frac{1+a}{2a}$	$\frac{x^2 a}{1+a}$	x^μ $\quad a \equiv \sqrt{1+\frac{m^2x^2}{(x\cdot p)^2}}$
$p^2 + m^2 = 0$	$P^M =$	$\frac{-m^2}{2a\, x\cdot p}$	$a\ x\cdot p$	p^μ

Make 2 gauge choices. Solve 2 constraints. Remains 1 gauge choice and 1 constraint

$X\cdot X = X\cdot P = P\cdot P = 0$ $\quad ds^2 = dX^M dX^N \eta_{MN} = -2dX^{+'}dX^{-'} + dX^\mu dX^\nu \eta_{\mu\nu}$ $\quad X^{\pm'} = \frac{1}{\sqrt{2}}\left(X^{0'} \pm X^{1'}\right)$

		$X^{+'}(\tau)$ / $P^{+'}(\tau)$	$X^{-'}(\tau)$ / $P^{-'}(\tau)$	$X^\mu(\tau)$ / $P^\mu(\tau)$
Relativistic massless particle	$X^M =$	1	$\frac{1}{2}x^2$	x^μ
$p^2 = 0$	$P^M =$	0	$x\cdot p$	p^μ
Relativistic massive particle	$X^M =$	$\frac{1+a}{2a}$	$\frac{x^2 a}{1+a}$	x^μ $\quad a \equiv \sqrt{1+\frac{m^2 x^2}{(x\cdot p)^2}}$
$p^2 + m^2 = 0$	$P^M =$	$\frac{-m^2}{2a x\cdot p}$	$a\ x\cdot p$	p^μ
Non-relativistic massive particle	$X^M =$	t	$\frac{\mathbf{r}\cdot\mathbf{p}-tH}{m}$	$X^0 = \pm\left\|\mathbf{r}-\frac{t}{m}\mathbf{p}\right\|,\ X^i = \mathbf{r}^i$
$H - \frac{\mathbf{p}^2}{2m} = 0$	$P^M =$	m	H	$P^0 = 0,\ P^i = \mathbf{p}^i$

Make 2 gauge choices. Solve 2 constraints. Remains 1 gauge choice and 1 constraint

$X \cdot X = X \cdot P = P \cdot P = 0$ $\quad ds^2 = dX^M dX^N \eta_{MN} = -2dX^{+'} dX^{-'} + dX^\mu dX^\nu \eta_{\mu\nu}$ $\quad X^{\pm'} = \frac{1}{\sqrt{2}}\left(X^{0'} \pm X^{1'}\right)$

		$X^{+'}(\tau)$ / $P^{+'}(\tau)$	$X^{-'}(\tau)$ / $P^{-'}(\tau)$	$X^\mu(\tau)$ / $P^\mu(\tau)$
Relativistic massless particle	$X^M =$	1	$\frac{1}{2}x^2$	x^μ
$p^2 = 0$	$P^M =$	0	$x \cdot p$	p^μ
Relativistic massive particle	$X^M =$	$\frac{1+a}{2a}$	$\frac{x^2 a}{1+a}$	x^μ $\quad a \equiv \sqrt{1+\frac{m^2 x^2}{(x \cdot p)^2}}$
$p^2 + m^2 = 0$	$P^M =$	$\frac{-m^2}{2a x \cdot p}$	$a\ x \cdot p$	p^μ
Non-relativistic massive particle	$X^M =$	t	$\frac{\mathbf{r} \cdot \mathbf{p} - tH}{m}$	$X^0 = \pm\left\lvert \mathbf{r} - \frac{t}{m}\mathbf{p} \right\rvert,\ X^i = \mathbf{r}^i$
$H - \frac{\mathbf{p}^2}{2m} = 0$	$P^M =$	m	H	$P^0 = 0,\ P^i = \mathbf{p}^i$

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Mass : modulus in the embedding of d-dimensional phase space into d+2.

$X \cdot X = X \cdot P = P \cdot P = 0$ $\quad ds^2 = dX^M dX^N \eta_{MN} = -2dX^{+'} dX^{-'} + dX^\mu dX^\nu \eta_{\mu\nu} \quad X^{\pm'} = \frac{1}{\sqrt{2}}(X^{0'} \pm X^{1'})$

		$X^{+'}(\tau)$, $P^{+'}(\tau)$	$X^{-'}(\tau)$, $P^{-'}(\tau)$	$X^\mu(\tau)$, $P^\mu(\tau)$
Relativistic massless particle	$X^M =$	1	$\frac{1}{2}x^2$	x^μ
$p^2 = 0$	$P^M =$	0	$x \cdot p$	p^μ
Relativistic massive particle	$X^M =$	$\frac{1+a}{2a}$	$\frac{x^2 a}{1+a}$	$x^\mu \quad a \equiv \sqrt{1+\frac{m^2 x^2}{(x \cdot p)^2}}$
$p^2 + m^2 = 0$	$P^M =$	$\frac{-m^2}{2a x \cdot p}$	$a\ x \cdot p$	p^μ
Non-relativistic massive particle	$X^M =$	t	$\frac{\mathbf{r} \cdot \mathbf{p} - tH}{m}$	$X^0 = \pm \left\vert \mathbf{r} - \frac{t}{m}\mathbf{p} \right\vert, \ X^i = \mathbf{r}^i$
$H - \frac{\mathbf{p}^2}{2m} = 0$	$P^M =$	m	H	$P^0 = 0, \ P^i = \mathbf{p}^i$
Maximally Symmetric Spaces	$X^M =$	$1+\sqrt{1-Kx^2}$	$\frac{x^2/2}{1+\sqrt{1-Kx^2}}$	$x^\mu \quad g_{\mu\nu} = \eta_{\mu\nu} + \frac{K}{1-Kx^2} x_\mu x_\nu$
$p^2 - \frac{K(x \cdot p)^2}{1-Kx^2} = 0$	$P^M =$	0	$\frac{\sqrt{1-Kx^2}}{1+\sqrt{1-Kx^2}} x \cdot p$	$p^\mu - \frac{K x \cdot p\ x^\mu}{1+\sqrt{1-Kx^2}}$

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Make 2 gauge choices. Solve 2 constraints. Remains 1 gauge choice and 1 constraint

		$X^{+'}(\tau)$ / $P^{+'}(\tau)$	$X^{-'}(\tau)$ / $P^{-'}(\tau)$	$X^{\mu}(\tau)$ / $P^{\mu}(\tau)$
Relativistic massless particle	$X^M =$	1	$\frac{1}{2}x^2$	x^μ
$p^2 = 0$	$P^M =$	0	$x\cdot p$	p^μ
Relativistic massive particle	$X^M =$	$\frac{1+a}{2a}$	$\frac{x^2 a}{1+a}$	x^μ $\quad a \equiv \sqrt{1+\frac{m^2x^2}{(x\cdot p)^2}}$
$p^2 + m^2 = 0$	$P^M =$	$\frac{-m^2}{2a\,x\cdot p}$	$a\;x\cdot p$	p^μ
Non-relativistic massive particle	$X^M =$	t	$\frac{\mathbf{r}\cdot\mathbf{p}-tH}{m}$	$X^0 = \pm\left\lvert\mathbf{r}-\frac{t}{m}\mathbf{p}\right\rvert,\; X^i = \mathbf{r}^i$
$H - \frac{\mathbf{p}^2}{2m} = 0$	$P^M =$	m	H	$P^0 = 0,\; P^i = \mathbf{p}^i$
Maximally Symmetric Spaces	$X^M =$	$1+\sqrt{1-Kx^2}$	$\frac{x^2/2}{1+\sqrt{1-Kx^2}}$	x^μ $\quad g_{\mu\nu} = \eta_{\mu\nu} + \frac{K}{1-Kx^2}x_\mu x_\nu$
$p^2 - \frac{K\,(x\cdot p)^2}{1-Kx^2} = 0$	$P^M =$	0	$\frac{\sqrt{1-Kx^2}}{1+\sqrt{1-Kx^2}}x\cdot p$	$p^\mu - \frac{K\,x\cdot p\;x^\mu}{1+\sqrt{1-Kx^2}}$

Mass : modulus in the embedding of d-dimensional phase space into d+2.

curvature

$X\cdot X = X\cdot P = P\cdot P = 0$ $\quad ds^2 = dX^M dX^N \eta_{MN} = -2dX^{+'}dX^{-'} + dX^\mu dX^\nu \eta_{\mu\nu}$ $\quad X^{\pm'} = \frac{1}{\sqrt{2}}\left(X^{0'} \pm X^{1'}\right)$

		$X^{+'}(\tau)$ / $P^{+'}(\tau)$	$X^{-'}(\tau)$ / $P^{-'}(\tau)$	$X^{\mu}(\tau)$ / $P^{\mu}(\tau)$
Relativistic massless particle	$X^M =$	1	$\frac{1}{2}x^2$	x^μ
$p^2 = 0$	$P^M =$	0	$x\cdot p$	p^μ
Relativistic massive particle	$X^M =$	$\frac{1+a}{2a}$	$\frac{x^2 a}{1+a}$	x^μ $\quad a \equiv \sqrt{1+\frac{m^2x^2}{(x\cdot p)^2}}$
$p^2 + m^2 = 0$	$P^M =$	$\frac{-m^2}{2a\,x\cdot p}$	$a\ x\cdot p$	p^μ
Non-relativistic massive particle	$X^M =$	t	$\frac{\mathbf{r}\cdot\mathbf{p}-tH}{m}$	$X^0 = \pm\left\vert\mathbf{r}-\frac{t}{m}\mathbf{p}\right\vert,\ X^i = \mathbf{r}^i$
$H - \frac{\mathbf{p}^2}{2m} = 0$	$P^M =$	m	H	$P^0 = 0,\ P^i = \mathbf{p}^i$

Make 2 gauge choices. Solve 2 constraints. Remains 1 gauge choice and 1 constraint

Mass : modulus in the embedding of d-dimensional phase space into d+2.

Maximally Symmetric Spaces	$X^M =$	$1+\sqrt{1-Kx^2}$	$\frac{x^2/2}{1+\sqrt{1-Kx^2}}$	x^μ $\quad g_{\mu\nu} = \eta_{\mu\nu} + \frac{K}{1-Kx^2}x_\mu x_\nu$
$p^2 - \frac{K(x\cdot p)^2}{1-Kx^2} = 0$	$P^M =$	0	$\frac{\sqrt{1-Kx^2}}{1+\sqrt{1-Kx^2}}x\cdot p$	$p^\mu - \frac{K\,x\cdot p\ x^\mu}{1+\sqrt{1-Kx^2}}$

curvature

*Time and Hamiltonian are different in each case <-> 1T perspectives in 2T phase space. All can be gauge transformed to each other. **There are gauge invariant relations among them**. **(info absent in 1T-physics)***

Any function of $L^{MN}=X^MP^N-X^NP^M$ is gauge invariant

Gauge choice	M	$0'$ ($X^{0'}$)	0 (X^{0})	$I=(1',i)$ ($X^{1'}\ X^{i}$)
Robertson-Walker $r<R_0$ (closed universe)	$X^M =$	$a(t)\cos(\int^t \frac{dt'}{a(t')})$	$a(t)\sin(\int^t \frac{dt'}{a(t')})$	$X^i = r^i a(t)/R_0$ $X^{1'} = \pm a(t)\sqrt{1-\frac{r^2}{R_0^2}}$
$-H^2+\frac{R_0^2}{a^2(t)}(\mathbf{p}^2-\frac{(\mathbf{r}\cdot\mathbf{p})^2}{R_0^2})=0$	$P^M =$	$-H\sin(\int^t \frac{dt'}{a(t')})$	$H\cos(\int^t \frac{dt'}{a(t')})$	$P^i = \frac{R_0}{a(t)}(\mathbf{p}^i - \frac{\mathbf{r}\cdot\mathbf{p}}{R_0^2}\mathbf{r}^i)$ $P^{1'} = \pm\frac{\mathbf{r}\cdot\mathbf{p}}{a(t)}\sqrt{1-\frac{r^2}{R_0^2}}$
Robertson-Walker $r>0$ (open universe)	$X^M =$	$a(t)\sinh(\int^t \frac{dt'}{a(t')})$	$(\pm)' a(t)\sqrt{1+\frac{r^2}{R_0^2}}$	$X^i = r^i a(t)/R_0$ $X^{1'} = \pm a(t)\cosh(\int^t \frac{dt'}{a(t')})$
$-H^2+\frac{R_0^2}{a^2(t)}(\mathbf{p}^2+\frac{(\mathbf{r}\cdot\mathbf{p})^2}{R_0^2})=0$	$P^M =$	$\pm H\cosh(\int^t \frac{dt'}{a(t')})$	$(\pm)'\frac{\mathbf{r}\cdot\mathbf{p}}{a(t)}\sqrt{1+\frac{r^2}{R_0^2}}$	$P^i = \frac{R_0}{a(t)}(\mathbf{p}^i + \frac{\mathbf{r}\cdot\mathbf{p}}{R_0^2}\mathbf{r}^i)$ $P^{1'} = H\sinh(\int^t \frac{dt'}{a(t')})$
Cosmological constant $\Lambda\equiv\frac{3}{R_0^2}>0$	$X^M =$	$\sqrt{R_0^2-r^2}\sinh\frac{t}{R_0}$	R_0	$X^i = \mathbf{r}^i$ $X^{1'} = \pm\sqrt{R_0^2-r^2}\cosh\frac{t}{R_0}$
$-H^2(1-\frac{r^2}{R_0^2})+(\mathbf{p}^2+\frac{(\mathbf{r}\cdot\mathbf{p})^2}{R_0^2-r^2})=0$	$P^M =$	$\pm\frac{H}{R_0}\sqrt{R_0^2-r^2}\cosh\frac{t}{R_0}$	$\frac{R_0\mathbf{r}\cdot\mathbf{p}}{R_0^2-r^2}$	$P^i = \mathbf{p}^i + \frac{\mathbf{r}\cdot\mathbf{p}}{R_0^2-r^2}\mathbf{r}^i$ $P^{1'} = \frac{H}{R_0}\sqrt{R_0^2-r^2}\sinh\frac{t}{R_0}$
Cosmological constant $\Lambda\equiv-\frac{3}{R_0^2}<0$	$X^M =$	$\sqrt{R_0^2+r^2}\sin\frac{t}{R_0}$	$\pm\sqrt{R_0^2+r^2}\cos\frac{t}{R_0}$	$X^i = \mathbf{r}^i$ $X^{1'} = R_0$
$-H^2(1+\frac{r^2}{R_0^2})+(\mathbf{p}^2-\frac{(\mathbf{r}\cdot\mathbf{p})^2}{R_0^2+r^2})=0$	$P^M =$	$\pm\frac{H}{R_0}\sqrt{R_0^2+r^2}\cos\frac{t}{R_0}$	$\frac{H}{R_0}\sqrt{R_0^2+r^2}\sin\frac{t}{R_0}$	$P^i = \mathbf{p}^i - \frac{\mathbf{r}\cdot\mathbf{p}}{R_0^2+r^2}\mathbf{r}^i$ $P^{1'} = -\frac{R_0\mathbf{r}\cdot\mathbf{p}}{R_0^2+r^2}$
(d−1)-sphere × time	$X^M =$	$R_0\cos\frac{t}{R_0}$	$R_0\sin\frac{t}{R_0}$	$R_0\hat{n}^I =$ $X^i = \mathbf{r}^i$, $X^{1'} = \pm\sqrt{R_0^2-r^2}$
$-H^2+(\mathbf{p}^2+\frac{(\mathbf{r}\cdot\mathbf{p})^2}{R_0^2-r^2})=0$	$P^M =$	$-H\sin\frac{t}{R_0}$	$H\cos\frac{t}{R_0}$	$P^i = \mathbf{p}^i$ $P^{1'} = \mp\frac{\mathbf{r}\cdot\mathbf{p}}{\sqrt{R_0^2-r^2}}$
H-atom, $H<0$	$X^M =$	$r\cos u$ $u(t)\equiv\frac{\sqrt{-2mH}}{m\alpha}(\mathbf{r}\cdot\mathbf{p}-2mHt)$	$r\sin u$	$X^i = \mathbf{r}^i - \frac{r}{m\alpha}\mathbf{r}\cdot\mathbf{p}\ \mathbf{p}^i$ $X^{1'} = -\frac{r}{m\alpha}\sqrt{-2mH}\,\mathbf{r}\cdot\mathbf{p}$
$H=\frac{\mathbf{p}^2}{2m}-\frac{\alpha}{r}$	$P^M =$	$-\frac{m\alpha}{r\sqrt{-2mH}}\sin u$	$\frac{m\alpha}{r\sqrt{-2mH}}\cos u$	$P^i = \mathbf{p}^i$ $P^{1'} = \frac{1}{\sqrt{-2mH}}(\frac{m\alpha}{r}-\mathbf{p}^2)$
H-atom, $H>0$	$X^M =$	$r\cosh u$ $u(t)\equiv\frac{\sqrt{2mH}}{m\alpha}(\mathbf{r}\cdot\mathbf{p}-2mHt)$	$\frac{r}{m\alpha}\sqrt{2mH}\,\mathbf{r}\cdot\mathbf{p}$	$X^i = \mathbf{r}^i - \frac{r}{m\alpha}\mathbf{r}\cdot\mathbf{p}\ \mathbf{p}^i$ $X^{1'} = r\sinh u$
	$P^M =$	$\frac{m\alpha}{r\sqrt{2mH}}\sinh u$	$\frac{1}{\sqrt{2mH}}(\frac{m\alpha}{r}-\mathbf{p}^2)$	$P^i = \mathbf{p}^i$ $P^{1'} = \frac{m\alpha}{r\sqrt{2mH}}\cosh u$

An example: Massive relativistic particle gauge

$$X^{\pm'} = \frac{1}{\sqrt{2}}\left(X^{0'} \pm X^{1'}\right) \qquad ds^2 = dX^M dX^N \eta_{MN} = -2dX^{+'}dX^{-'} + dX^\mu dX^\nu \eta_{\mu\nu}$$

$$X^M = \left(\overset{+'}{\frac{1-a}{2a}},\ \overset{-'}{\frac{x^2 a}{1+a}},\ \overset{\mu}{x^\mu} \right),\ a \equiv \sqrt{1 + \frac{m^2 x^2}{(x\cdot p)^2}}$$

Note a=1 when m=0

$$P^M = \left(\frac{-m^2}{2(x\cdot p)a},\ (x\cdot p)\,a\ ,\ p^\mu \right),\ P^2 = p^2 + m^2 = 0.$$

embed phase space in 3+1 into phase space in 4+2

Make 2 gauge choices solve 2 constraints X^2=X.P=0

τ reparametrization and one constraint remains.

$$S = \int d\tau \left(\dot{X}^M P^N - \frac{1}{2} A^{ij} X_i^M X_j^N \right) \eta_{MN} = \int d\tau \left(\dot{x}^\mu p_\mu - \frac{1}{2} A^{22} \left(p^2 + m^2\right) \right)$$

An example: Massive relativistic particle gauge

$$X^{\pm'} = \frac{1}{\sqrt{2}}\left(X^{0'} \pm X^{1'}\right) \qquad ds^2 = dX^M dX^N \eta_{MN} = -2dX^{+'}dX^{-'} + dX^\mu dX^\nu \eta_{\mu\nu}$$

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$$P^M = \left(\frac{-m^2}{2(x\cdot p)a},\ (x\cdot p)\,a\ ,\ p^\mu \right),\ P^2 = p^2 + m^2 = 0.$$

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embed phase space in 3+1 into phase space in 4+2

Make 2 gauge choices solve 2 constraints $X^2 = X.P = 0$

τ reparametrization and one constraint remains.

Gauge invariants

$$S = \int d\tau \left(\dot{X}^M P^N - \frac{1}{2} A^{ij} X_i^M X_j^N \right) \eta_{MN} = \int d\tau \left(\dot{x}^\mu p_\mu - \frac{1}{2} A^{22}\left(p^2 + m^2\right) \right)$$

$$L^{MN} = \varepsilon^{ij} X_i^M X_j^N = X^M P^N - X^N P^M$$

⇒

$$L^{\mu\nu} = x^\mu p^\nu - x^\nu p^\mu,\quad L^{+'-'} = (x\cdot p)\,a,$$

$$L^{+'\mu} = \frac{1+a}{2a} p^\mu - \frac{m^2}{2(x\cdot p)a} x^\mu$$

$$L^{-'\mu} = \frac{x^2 a}{1+a} p^\mu - (x\cdot p)\,a x^\mu$$

$X\cdot X = X\cdot P = P\cdot P = 0$ $\quad ds^2 = dX^M dX^N \eta_{MN} = -2dX^{+'}dX^{-'} + dX^\mu dX^\nu \eta_{\mu\nu}$ $\quad X^{\pm'} = \frac{1}{\sqrt{2}}\left(X^{0'} \pm X^{1'}\right)$

		$X^{+'}(\tau)$ / $P^{+'}(\tau)$	$X^{-'}(\tau)$ / $P^{-'}(\tau)$	$X^{\mu}(\tau)$ / $P^{\mu}(\tau)$
Relativistic massless particle	$X^M =$	1	$\frac{1}{2}x^2$	x^μ
$p^2 = 0$	$P^M =$	0	$x\cdot p$	p^μ
Relativistic massive particle	$X^M =$	$\frac{1+a}{2a}$	$\frac{x^2 a}{1+a}$	x^μ $\quad a \equiv \sqrt{1+\frac{m^2x^2}{(x\cdot p)^2}}$
$p^2 + m^2 = 0$	$P^M =$	$\frac{-m^2}{2a\,x\cdot p}$	$a\ x\cdot p$	p^μ
Non-relativistic massive particle	$X^M =$	t	$\frac{\mathbf{r}\cdot\mathbf{p}-tH}{m}$	$X^0 = \pm\left\lvert \mathbf{r}-\frac{t}{m}\mathbf{p}\right\rvert,\ X^i = \mathbf{r}^i$
$H - \frac{\mathbf{p}^2}{2m} = 0$	$P^M =$	m	H	$P^0 = 0,\ P^i = \mathbf{p}^i$

Make 2 gauge choices. Solve 2 constraints. Remains 1 gauge choice and 1 constraint

Mass : modulus in the embedding of d-dimensional phase space into d+2.

Maximally Symmetric Spaces	$X^M =$	$1+\sqrt{1-Kx^2}$	$\frac{x^2/2}{1+\sqrt{1-Kx^2}}$	x^μ $\quad g_{\mu\nu} = \eta_{\mu\nu} + \frac{K}{1-Kx^2}x_\mu x_\nu$
$p^2 - \frac{K\,(x\cdot p)^2}{1-Kx^2} = 0$	$P^M =$	0	$\frac{\sqrt{1-Kx^2}}{1+\sqrt{1-Kx^2}}x\cdot p$	$p^\mu - \frac{K\,x\cdot p\ x^\mu}{1+\sqrt{1-Kx^2}}$

curvature

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Any function of LMN=XMPN−XNPM is gauge invariant

Gauge choice	M	$0'$ $X^{0'}$	0 X^0	$I=(1',i)$ $X^{1'}X^i$
Robertson-Walker $r<R_0$ (closed universe)	$X^M=$	$a(t)\cos(\int^t \frac{dt'}{a(t')})$	$a(t)\sin(\int^t \frac{dt'}{a(t')})$	$X^i=\mathbf{r}^i a(t)/R_0$ $X^{1'}=\pm a(t)\sqrt{1-\frac{r^2}{R_0^2}}$
$-H^2+\frac{R_0^2}{a^2(t)}(\mathbf{p}^2-\frac{(\mathbf{r}\cdot\mathbf{p})^2}{R_0^2})=0$	$P^M=$	$-H\sin(\int^t \frac{dt'}{a(t')})$	$H\cos(\int^t \frac{dt'}{a(t')})$	$P^i=\frac{R_0}{a(t)}(\mathbf{p}^i-\frac{\mathbf{r}\cdot\mathbf{p}}{R_0^2}\mathbf{r}^i)$ $P^{1'}=\pm\frac{\mathbf{r}\cdot\mathbf{p}}{a(t)}\sqrt{1-\frac{r^2}{R_0^2}}$
Robertson-Walker $r>0$ (open universe)	$X^M=$	$a(t)\sinh(\int^t \frac{dt'}{a(t')})$	$(\pm)'a(t)\sqrt{1+\frac{r^2}{R_0^2}}$	$X^i=\mathbf{r}^i a(t)/R_0$ $X^{1'}=\pm a(t)\cosh(\int^t \frac{dt'}{a(t')})$
$-H^2+\frac{R_0^2}{a^2(t)}(\mathbf{p}^2+\frac{(\mathbf{r}\cdot\mathbf{p})^2}{R_0^2})=0$	$P^M=$	$\pm H\cosh(\int^t \frac{dt'}{a(t')})$	$(\pm)'\frac{\mathbf{r}\cdot\mathbf{p}}{a(t)}\sqrt{1+\frac{r^2}{R_0^2}}$	$P^i=\frac{R_0}{a(t)}(\mathbf{p}^i+\frac{\mathbf{r}\cdot\mathbf{p}}{R_0^2}\mathbf{r}^i)$ $P^{1'}=H\sinh(\int^t \frac{dt'}{a(t')})$
Cosmological constant $\Lambda\equiv\frac{3}{R_0^2}>0$	$X^M=$	$\sqrt{R_0^2-r^2}\sinh\frac{t}{R_0}$	R_0	$X^i=\mathbf{r}^i$ $X^{1'}=\pm\sqrt{R_0^2-r^2}\cosh\frac{t}{R_0}$
$-H^2(1-\frac{r^2}{R_0^2})+(\mathbf{p}^2+\frac{(\mathbf{r}\cdot\mathbf{p})^2}{R_0^2-r^2})=0$	$P^M=$	$\pm\frac{H}{R_0}\sqrt{R_0^2-r^2}\cosh\frac{t}{R_0}$	$\frac{R_0\mathbf{r}\cdot\mathbf{p}}{R_0^2-r^2}$	$P^i=\mathbf{p}^i+\frac{\mathbf{r}\cdot\mathbf{p}}{R_0^2-r^2}\mathbf{r}^i$ $P^{1'}=\frac{H}{R_0}\sqrt{R_0^2-r^2}\sinh\frac{t}{R_0}$
Cosmological constant $\Lambda\equiv-\frac{3}{R_0^2}<0$	$X^M=$	$\sqrt{R_0^2+r^2}\sin\frac{t}{R_0}$	$\pm\sqrt{R_0^2+r^2}\cos\frac{t}{R_0}$	$X^i=\mathbf{r}^i$ $X^{1'}=R_0$
$-H^2(1+\frac{r^2}{R_0^2})+(\mathbf{p}^2-\frac{(\mathbf{r}\cdot\mathbf{p})^2}{R_0^2+r^2})=0$	$P^M=$	$\pm\frac{H}{R_0}\sqrt{R_0^2+r^2}\cos\frac{t}{R_0}$	$\frac{H}{R_0}\sqrt{R_0^2+r^2}\sin\frac{t}{R_0}$	$P^i=\mathbf{p}^i-\frac{\mathbf{r}\cdot\mathbf{p}}{R_0^2+r^2}\mathbf{r}^i$ $P^{1'}=-\frac{R_0\mathbf{r}\cdot\mathbf{p}}{R_0^2+r^2}$
(d−1)-sphere × time	$X^M=$	$R_0\cos\frac{t}{R_0}$	$R_0\sin\frac{t}{R_0}$	$R_0\hat{n}^I=$ $X^i=\mathbf{r}^i$ $X^{1'}=\pm\sqrt{R_0^2-r^2}$
$-H^2+(\mathbf{p}^2+\frac{(\mathbf{r}\cdot\mathbf{p})^2}{R_0^2-r^2})=0$	$P^M=$	$-H\sin\frac{t}{R_0}$	$H\cos\frac{t}{R_0}$	$P^i=\mathbf{p}^i$ $P^{1'}=\pm\frac{\mathbf{r}\cdot\mathbf{p}}{\sqrt{R_0^2-r^2}}$
H-atom, $H<0$	$X^M=$	$r\cos u$ $u(t)\equiv\frac{\sqrt{-2mH}}{m\alpha}(\mathbf{r}\cdot\mathbf{p}-2mHt)$	$r\sin u$	$X^i=\mathbf{r}^i-\frac{r}{m\alpha}\mathbf{r}\cdot\mathbf{p}\,\mathbf{p}^i$ $X^{1'}=-\frac{r}{m\alpha}\sqrt{-2mH}\,\mathbf{r}\cdot\mathbf{p}$
$H=\frac{\mathbf{p}^2}{2m}-\frac{\alpha}{r}$	$P^M=$	$-\frac{m\alpha}{r\sqrt{-2mH}}\sin u$	$\frac{m\alpha}{r\sqrt{-2mH}}\cos u$	$P^i=\mathbf{p}^i$ $P^{1'}=\frac{1}{\sqrt{-2mH}}(\frac{m\alpha}{r}-\mathbf{p}^2)$
H-atom, $H>0$	$X^M=$	$r\cosh u$ $u(t)\equiv\frac{\sqrt{2mH}}{m\alpha}(\mathbf{r}\cdot\mathbf{p}-2mHt)$	$\frac{r}{m\alpha}\sqrt{2mH}\,\mathbf{r}\cdot\mathbf{p}$	$X^i=\mathbf{r}^i-\frac{r}{m\alpha}\mathbf{r}\cdot\mathbf{p}\,\mathbf{p}^i$ $X^{1'}=r\sinh u$
	$P^M=$	$\frac{m\alpha}{r\sqrt{2mH}}\sinh u$	$\frac{1}{\sqrt{2mH}}(\frac{m\alpha}{r}-\mathbf{p}^2)$	$P^i=\mathbf{p}^i$ $P^{1'}=\frac{m\alpha}{r\sqrt{2mH}}\cosh u$

An example: Massive relativistic particle gauge

$$X^{\pm'} = \frac{1}{\sqrt{2}}\left(X^{0'} \pm X^{1'}\right) \qquad ds^2 = dX^M dX^N \eta_{MN} = -2dX^{+'}dX^{-'} + dX^\mu dX^\nu \eta_{\mu\nu}$$

$$X^M = \left(\overset{+'}{\frac{1+a}{2a}},\ \overset{-'}{\frac{x^2 a}{1+a}},\ \overset{\mu}{x^\mu} \right),\quad a \equiv \sqrt{1 + \frac{m^2 x^2}{(x\cdot p)^2}}$$

Note a=1 when m=0

$$P^M = \left(\frac{-m^2}{2(x\cdot p)a},\ (x\cdot p)\,a\ ,\ p^\mu \right),\quad P^2 = p^2 + m^2 = 0.$$

embed phase space in 3+1 into phase space in 4+2

Make 2 gauge choices solve 2 constraints X^2=X.P=0

τ reparametrization and one constraint remains.

Gauge invariants

$$S = \int d\tau \left(\dot{X}^M P^N - \frac{1}{2} A^{ij} X_i^M X_j^N \right) \eta_{MN} = \int d\tau \left(\dot{x}^\mu p_\mu - \frac{1}{2} A^{22} \left(p^2 + m^2\right) \right)$$

$$L^{MN} = \varepsilon^{ij} X_i^M X_j^N = X^M P^N - X^N P^M$$

$$L^{\mu\nu} = x^\mu p^\nu - x^\nu p^\mu,\quad L^{+'-'} = (x\cdot p)\,a.$$

$$L^{+'\mu} = \frac{1+a}{2a} p^\mu - \frac{m^2}{2(x\cdot p)a} x^\mu$$

$$L^{-'\mu} = \frac{x^2 a}{1+a} p^\mu - (x\cdot p)\,a x^\mu$$

$\delta x^\mu = \omega_{MN}\{L^{MN}, x^\mu\}$, $\delta p^\mu = \omega_{MN}\{L^{MN}, p^\mu\}$,

SO(d,2) is **hidden symmetry** of the massive action. Looks like conformal tranformations deformed by mass. The symmetry in 1T theory is a clue of extra 1+1 dimensions, including 2T.

Shadows from 2T-physics ⇒ hidden info in 1T-physics

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2T-physics

Sp(2,R) gauge symm.

generators $Q_{ij}(X,P)$ vanish

simplest example

$X^2=P^2=X\cdot P=0 \rightarrow$ gauge inv.

space: flat 4+2 dims

SO(4,2) symmetry

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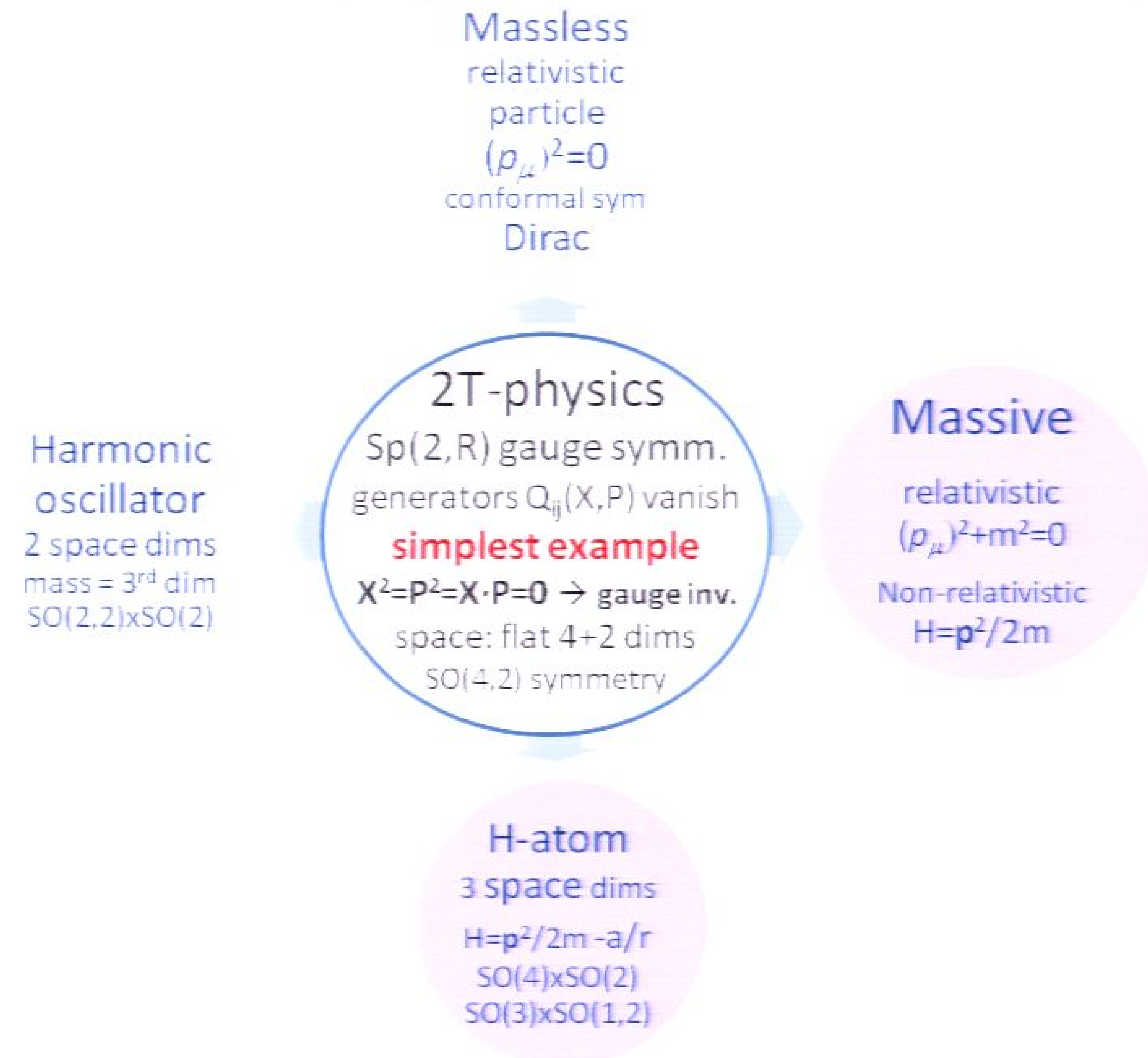

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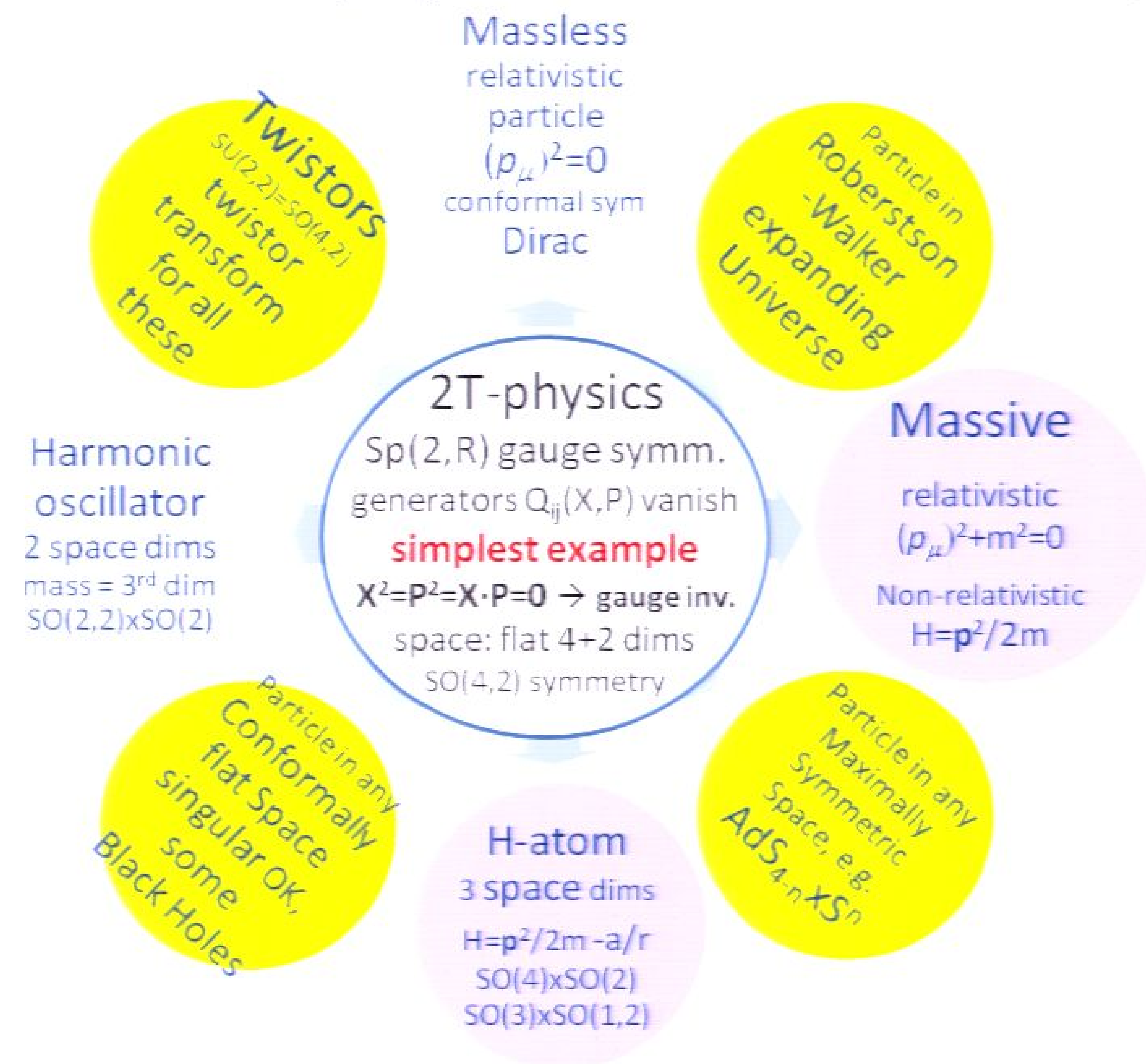

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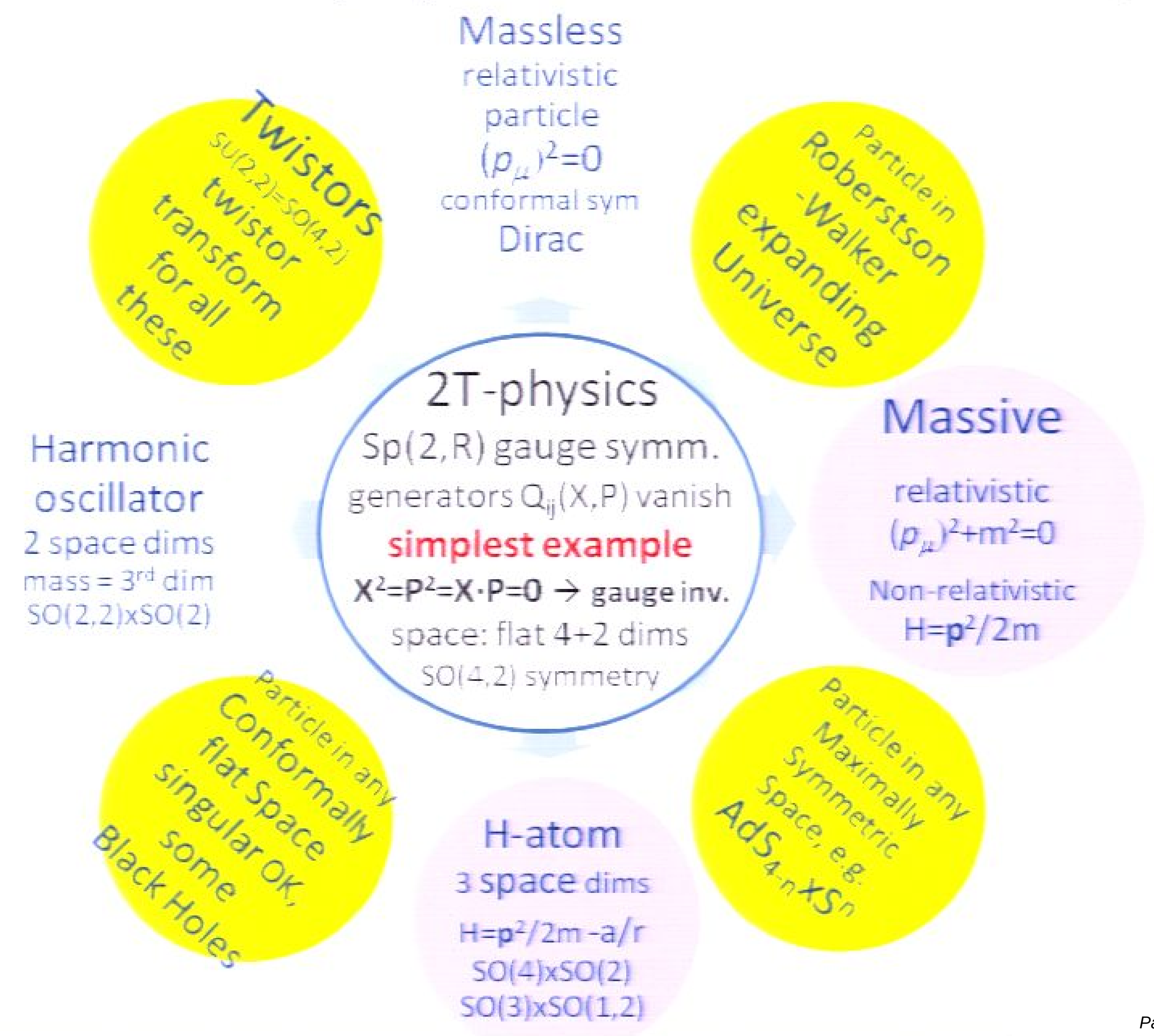
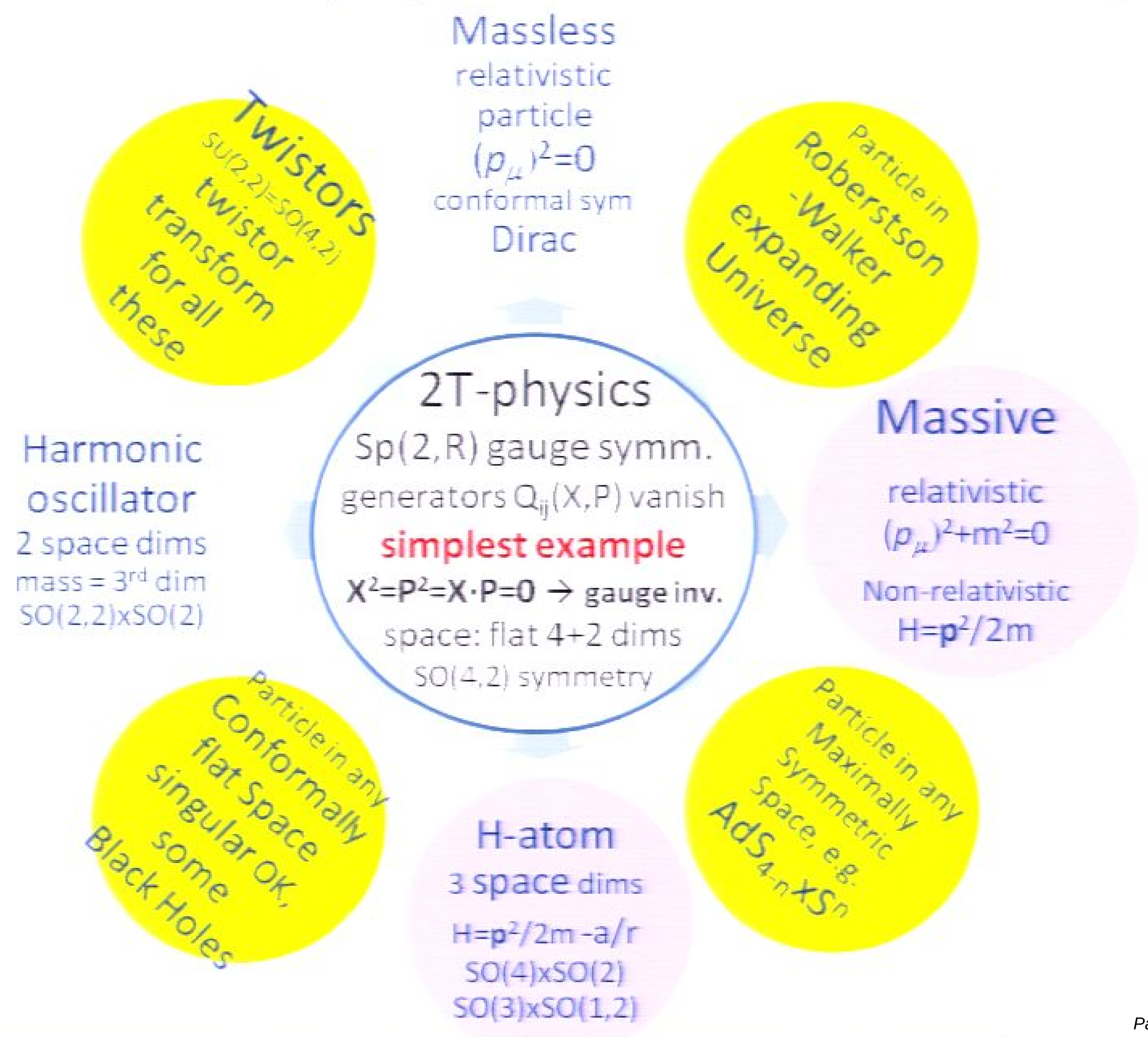


Shadows also for ∞ choices of $Q_{ij}(X,P)$, $H(X,P)$ & in 2T-field theory

Shadows from 2T-physics ⇒ hidden info in 1T-physics

Emergent spacetimes and emergent parameters: mass, couplings, curvature, etc.



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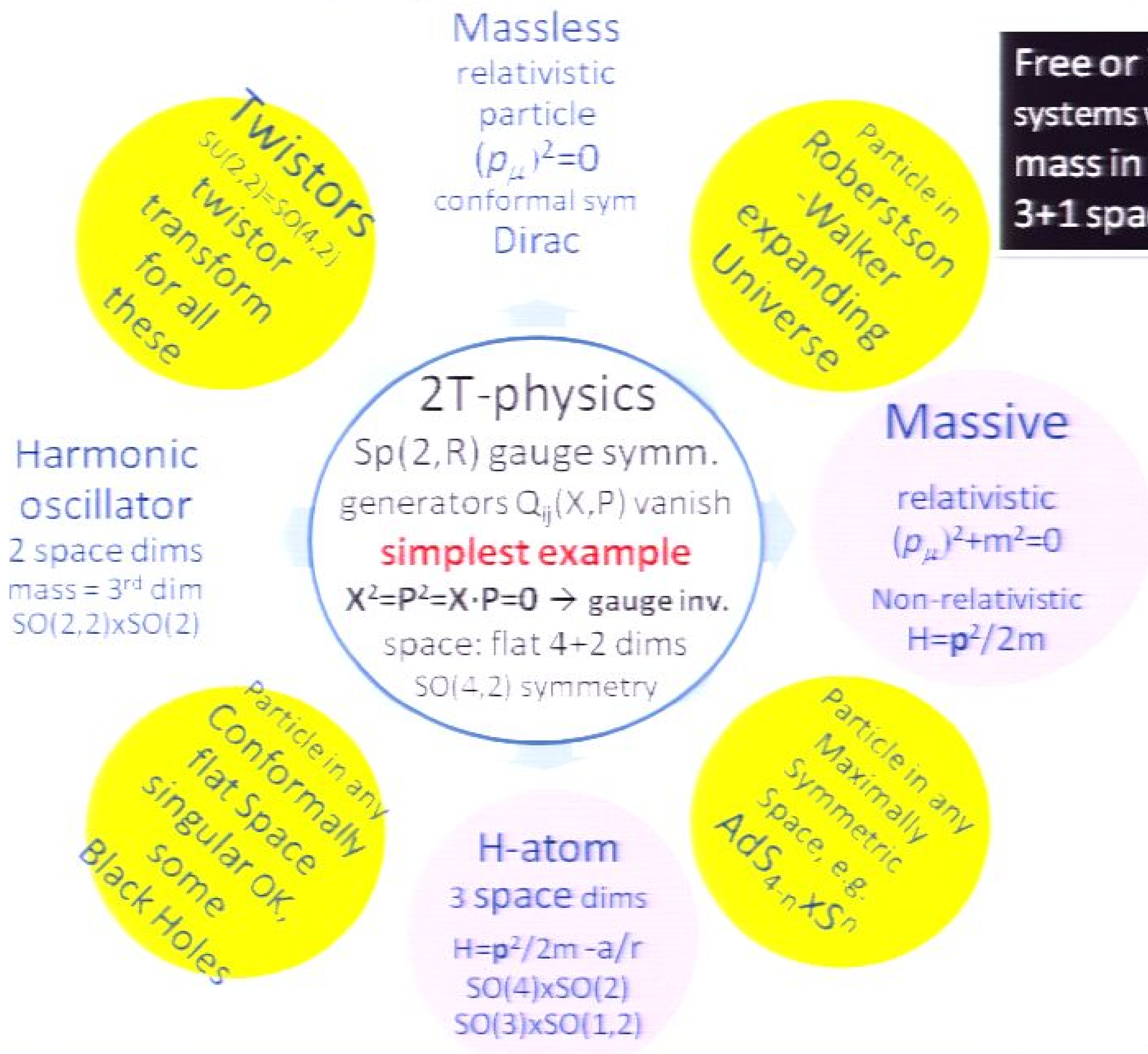
Shadows from 2T-physics ⇒ hidden info in 1T-physics

Free or interacting systems with/without mass in flat/curved 3+1 space-time

Emergent spacetimes and emergent parameters: mass, couplings, curvature, etc.



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Massless
relativistic
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$(p_\mu)^2=0$
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Twistors
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transform
for all
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Particle in
Roberstson
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Emergent
spacetimes
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Harmonic
oscillator
2 space dims
mass = 3rd dim
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"time" & Hamiltonian in 3+1 attributed to perspective of observers in 4+2 phase space

Particle in any
Conformally
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singular OK,
some
Black Holes

H-atom
3 space dims
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SO(3)xSO(1,2)

Particle in any
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$AdS_{4-n} \times S^n$

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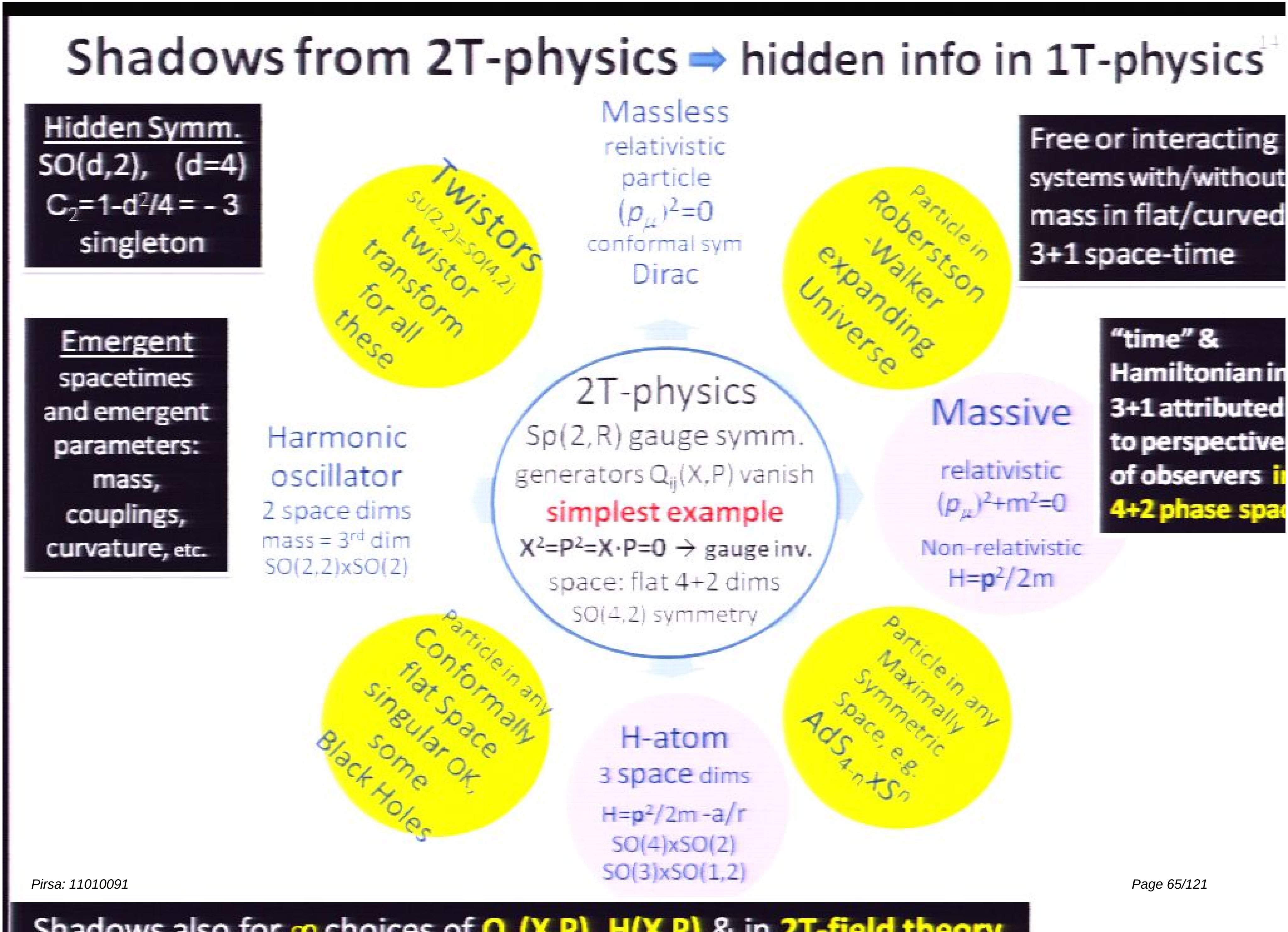

Shadows from 2T-physics ⇒ hidden info in 1T-physics
Hidden Symm.
SO(d,2), (d=4)
C_2=1-d^2/4 = - 3
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SO(4,2) symmetry
Harmonic oscillator
2 space dims
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2T-physics predicts hidden symmetries and dualities (with parameters) among the shadows

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Main points
1) **no ghosts:** 2T-physics is compatible with 1T-physics
2) **Systematic new info & insight** absent in

Shadows also for ∞ choices of $Q_{ij}(X,P)$, $H(X,P)$ & in 2T-field theory

How shadows might be used in “AdS-CFT” type correspondence

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Shadows from Flat 4+2, all have SO(4,2) in the same repr.

↓

Flat 3+1
Robertson-Walker 3+1
AdS_4
$AdS_3 x S^1$
$AdS_2 x S^2$
$R x S^3$
$deSitter_4$
All conf. flat spacetimes 4D
$H\text{-atom}_{3+1}$
$\text{Massive particles}_{3+1}$
Etc.

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The usual case AdS_5

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↓

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Robertson-Walker 4+1
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$AdS_3 x S^2$
$AdS_4 x S^1$
$R x S^4$
$deSitter_5$
All conf. flat in 5D
$H\text{-atom}_{4+1}$
Massive $particles_{4+1}$
Etc.

The usual case AdS_5 →

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Explore all of them take advantage of the established dualities among shadows

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Etc.

How shadows might be used in "AdS-CFT" type correspondence

Shadows from Flat 5+2, all have SO(5,2) in the same repr.

Explore directly in 2T formalism, then project down to shadows on both sides.

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2T Field Theory, including interactions.

- Physical states $Q_{ij}(X,\partial)\Phi(X)=0$ -- field eoms. Similar to Virasoro constraints in string theory.

  What is the action that generates these as eoms through the variational principle?

Gravity as background in 2T-p*h*ysics

0804.1585 [hep-th]

$$S = \int d\tau (\partial_\tau X^M P_M(\tau) - \frac{1}{2} A^{ij}(\tau)\, Q_{ij}(X(\tau), P(\tau)))$$

$$Q_{11} = W(X), \quad Q_{12} = V^M(X) P_M, \quad Q_{22} = G^{MN}(X) P_M P_N$$

Compare to flat case

$$Q_{11}^{flat} = X \cdot X, \quad Q_{12}^{flat} = X \cdot P, \quad Q_{22}^{flat} = P \cdot P,$$

$$W_{flat}(X) = X \cdot X, \quad V_{flat}^M(X) = X^M, \quad G_{flat}^{MN}(X) = \eta^{MN}$$

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$$\{Q_{11}, Q_{22}\} = 4Q_{12} \; \rightarrow V^M = \frac{1}{2} G^{MN} \partial_N W,$$

$$\{A, B\} \equiv \frac{\partial A}{\partial X^M} \frac{\partial B}{\partial P_M} + \frac{\partial A}{\partial P_M} \frac{\partial B}{\partial X^M}$$

$$\{Q_{11}, Q_{12}\} = 2Q_{11} \; \rightarrow \; V^M \partial_M W = 2W,$$

$$\{Q_{22}, Q_{12}\} = -2Q_{22} \; \rightarrow \; \pounds_V G^{MN} = -2G^{MN}$$

Sp(2,R) algebra puts kinematic constraints on background geometry

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Sp(2,R) algebra puts kinematic constraints on background geometry

$$-2G^{MN} = V^K \partial_K G^{MN} - \partial_K V^M G^{KN} - \partial_K V^N G^{MK}$$
$$= -\nabla^M V^N - \nabla^N V^M \equiv \pounds_V G^{MN}$$

$$G_{MN} = \nabla_M V_N = \frac{1}{2} \nabla_M \partial_N W$$

Solve kinematics, and impose $Q_{11}=Q_{12}=0$: Get all shadows, e.g.

$$S = \int d\tau \left(\partial_\tau x^\mu p_\mu(\tau) - \frac{1}{2} A^{22}(\tau)\; g^{\mu\nu}(x(\tau))\, p_\mu(\tau)\, p_\nu(\tau) \right)$$

Rules for 2T field theory, spins=0,½,1

Impose Sp(2,R) singlet condition in flat space !!

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Use BRST approach for Sp(2,R). Like string field theory: I.B.+Kuo, hep-th/0605267 I.B. hep-th/060645

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Flat space

$$S_{kin} = \int d^{d+2}X\,\delta(X^2)\left[\begin{array}{c}\frac{1}{2}\bar{\Phi}D^2\Phi + \frac{i}{2}\bar{\Psi}X\not{D}\Psi + h.c. \\ -\frac{1}{4}F_{MN}F^{MN}\,\Omega^{\frac{2(d-4)}{d-2}}\end{array}\right].$$

Ω is dilaton

Rules for 2T field theory, spins=0,½,1

Impose Sp(2,R) singlet condition in flat space !!

Use BRST approach for Sp(2,R). Like string field theory: I.B.+Kuo, hep-th/0605267; I.B. hep-th/060645

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Ω is dilaton

There is explicit X^M, no translation invariance, only **SO(d,2) spacetime invariance**. This SO(d,2) becomes conformal symmetry in the "conformal shadow", but a hidden SO(d,2) symmetry in other shadows.

$$S_{yukawa} = \int d^{d+2}X\,\delta(X^2)\,\Omega^{-\frac{d-4}{d-2}}\left[y\,(\bar{\Psi}_L X\Psi_R)\Phi + h.c.\right],$$

$\Psi_{L,R}$ spinors of $SO(d,2)$

Double the size spinor as SO(d-1,1) +Fermionic gauge sym

$$S_{scalars} = \int d^{d+2}X\,\delta(X^2)\,V(\Omega,\Phi),\qquad V(\Omega,H) = \Omega^{\frac{2d}{d-2}}V\left(1,\frac{\Phi}{\Omega}\right)$$

Homogeneous $V(\Omega,\Phi)$ Only dimensionless couplings among scalars

$$S_{anomalies} \sim \int d^{d+2}X\,\delta(X^2)\,\varepsilon^{M_1M_2M_3\cdots M_{d+2}}\,(X_{M_1}\partial_{M_2}\ln\Omega)\,(A_{M_3\cdots M_{d+2}})$$

Minimizing the action gives two equations, so get all 3 Sp(2,R) constraints for each field, including interaction !!

IB: 0804.1585
IB+S.H.Chen
0811.2510

Gravity & SM in 2T-physics Field Theory

Gauge symmetry and consistency with Sp(2,R) lead to a unique gravity action in d+2 dims, with **no parameters at all**.

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Pure gravity has three fields:
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$\Omega(X)$, dilaton
$W(X)$, appears in $\delta(W)$, and ...

$$S^0 = \gamma \int d^{d+2}X\sqrt{G}\left\{ \begin{array}{c} \delta(W)\left[\Omega^2 R(G) + \frac{1}{2a}\partial\Omega\cdot\partial\Omega - V(\Omega)\right] \\ +\delta'(W)\left[\Omega^2\left(4-\nabla^2 W\right) + \partial W\cdot\partial\Omega^2\right] \end{array} \right\}$$

No scale, $a = \frac{(d-2)}{8(d-1)}$.

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The equations of motion reproduce the Sp(2,R) constraints, called **kinematic equations**. (proportional to δ'(W), δ''(W)), and also the **dynamical equations** (proportional to δ(W)).

Progress in 2T-physics

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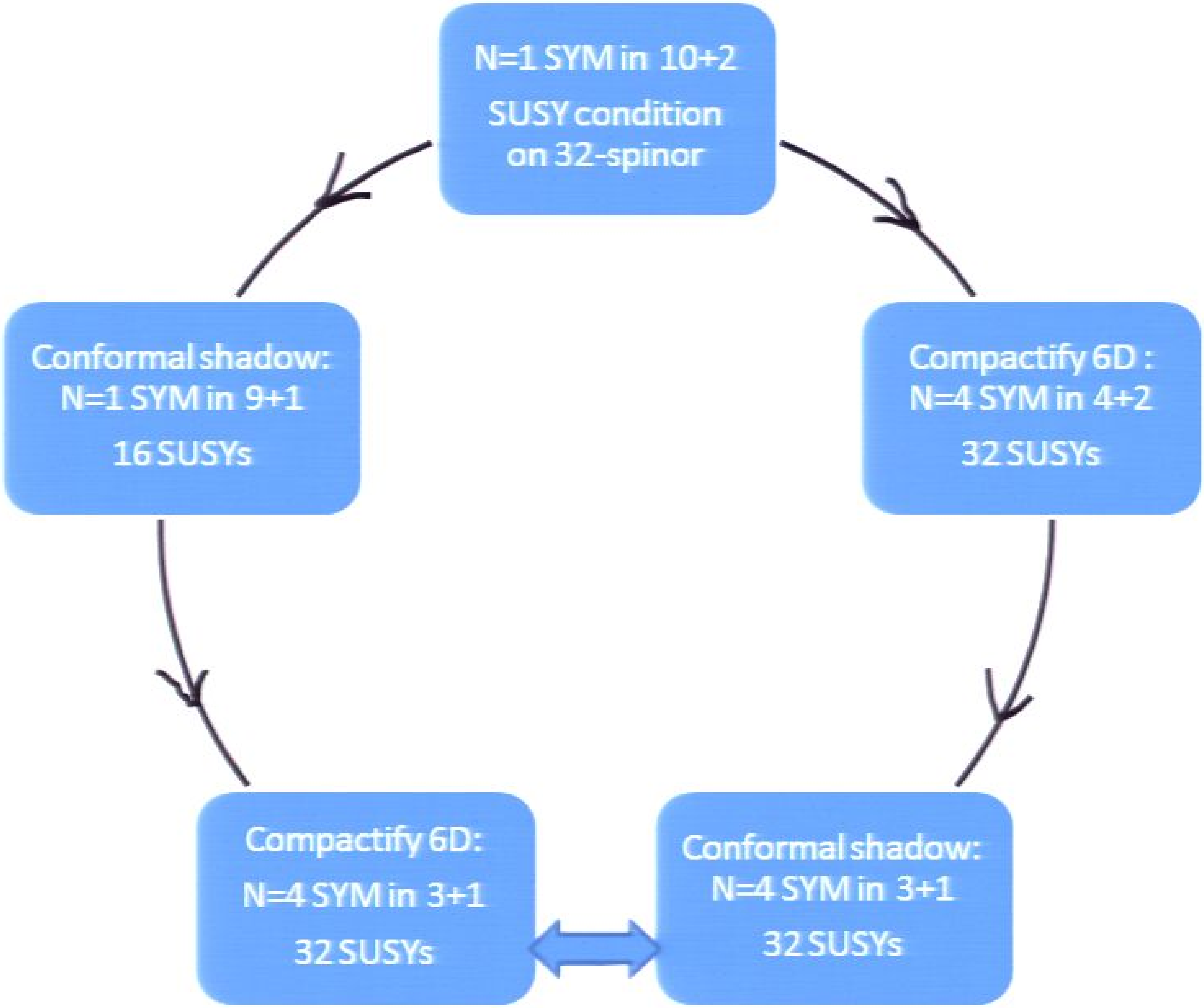
- **A more fundamental approach – field theory in phase space (full Q,P symm)**
  IB + Deliduman 0103042, IB + S.J.Rey 0104135, IB 0106013, + under development.

Green function

10+2 SYM as parent of N=4 SYM in 3+1, and a web of dualities



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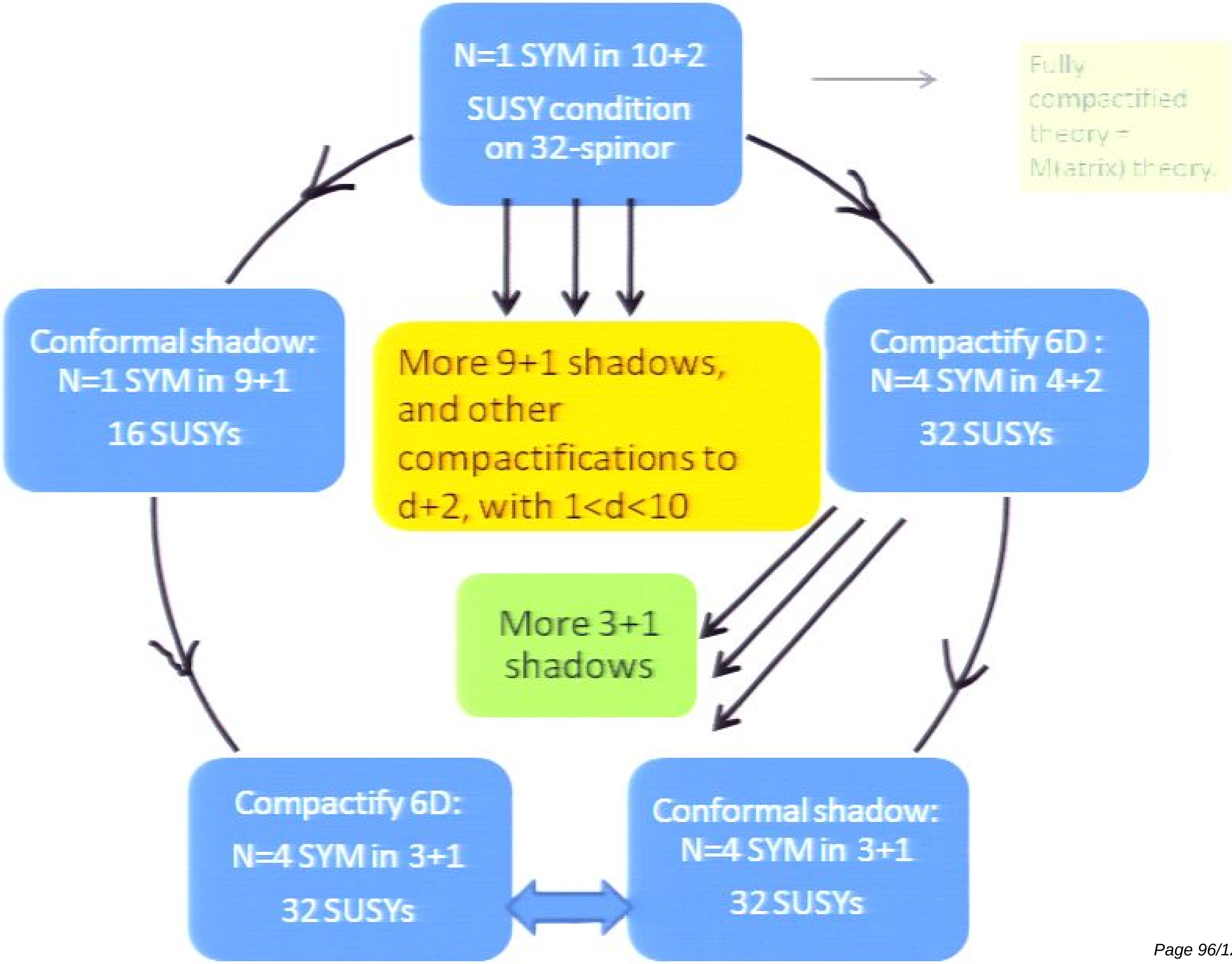

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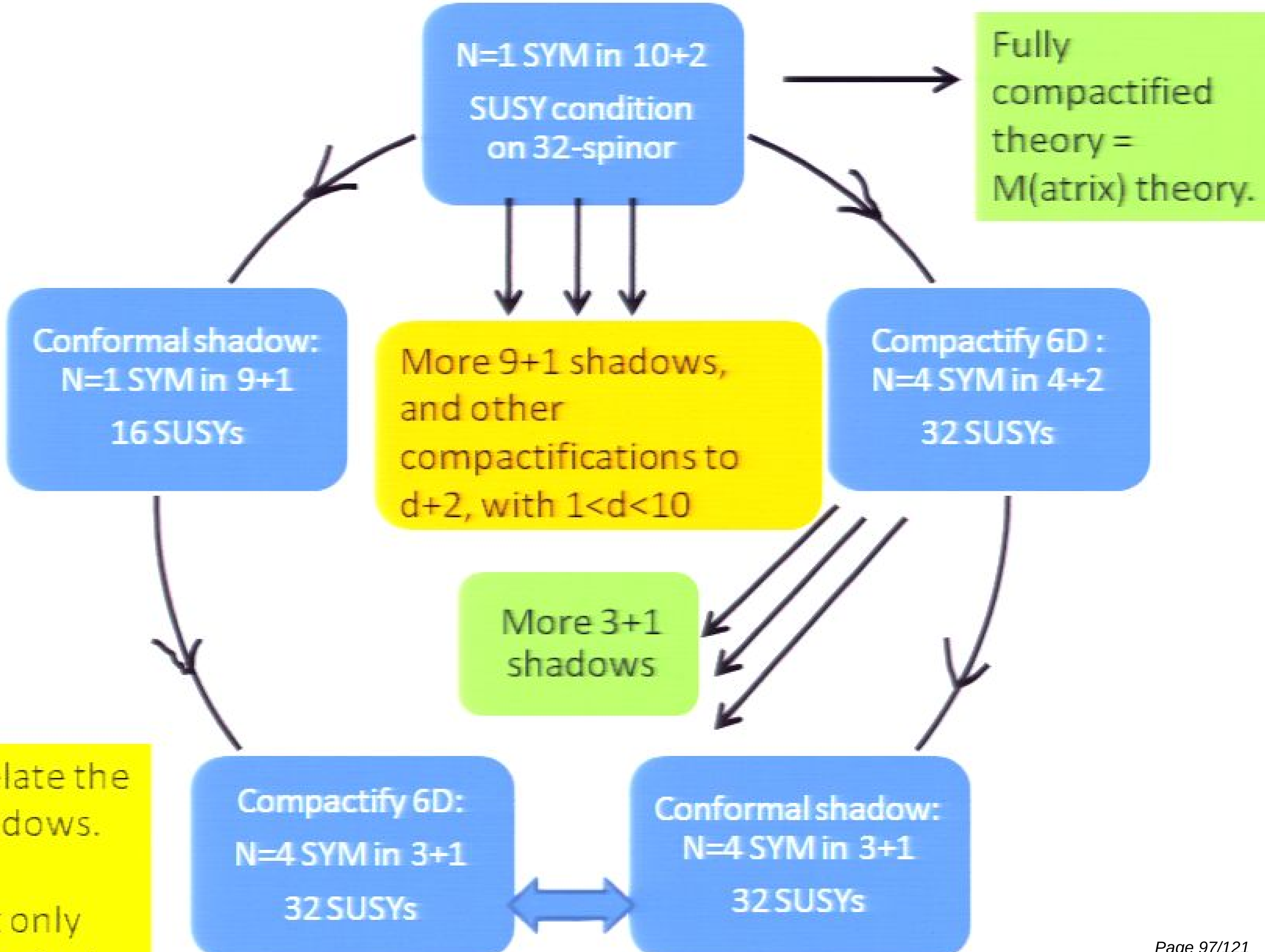

Dualities relate the various shadows.

This insight only from 2T-physics !

2T-Physics as a completion and unifying framework for 1T-physics

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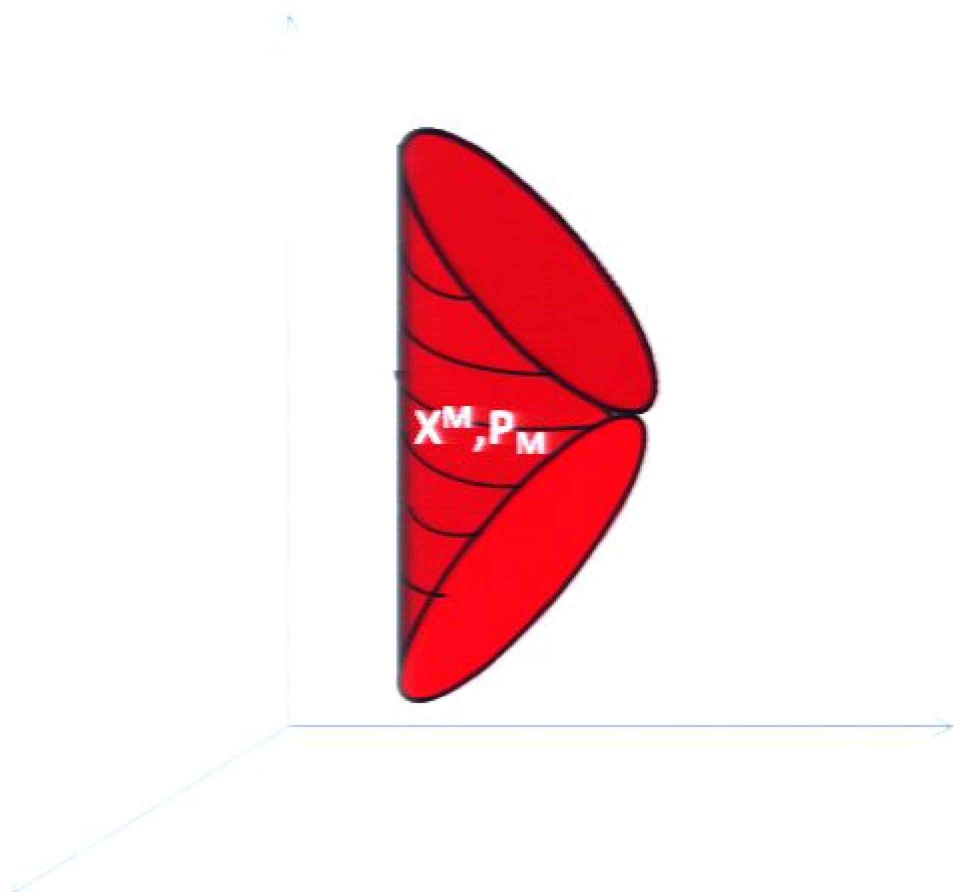

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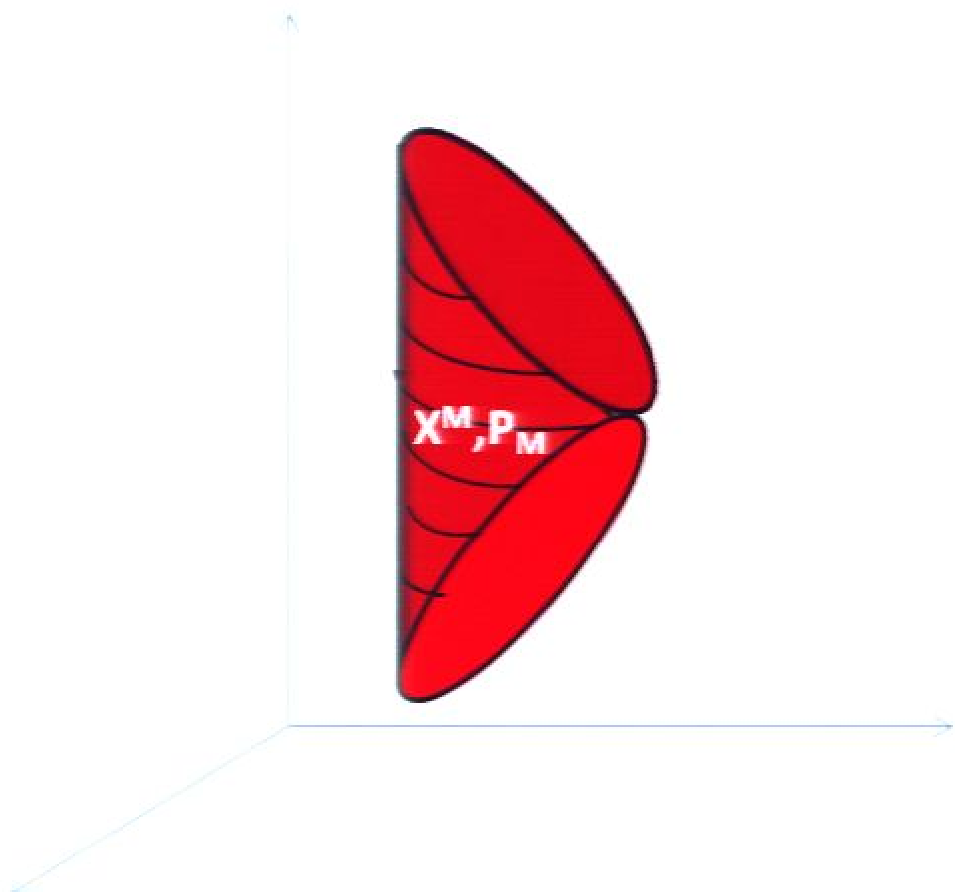

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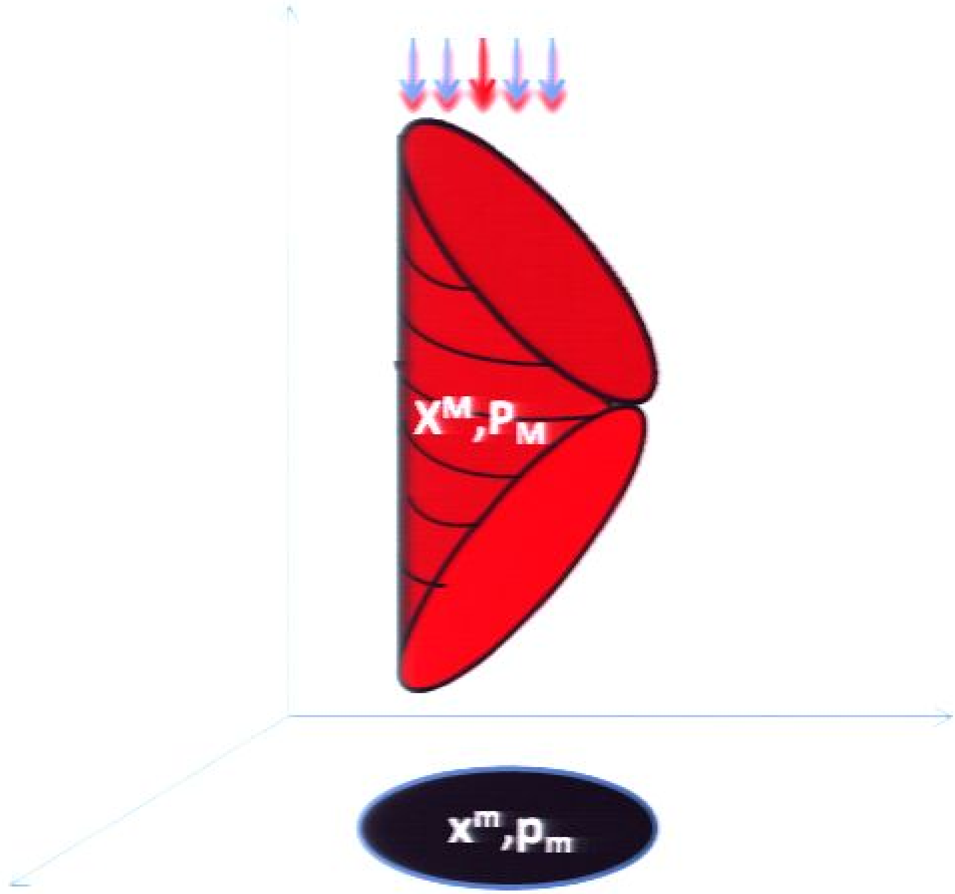

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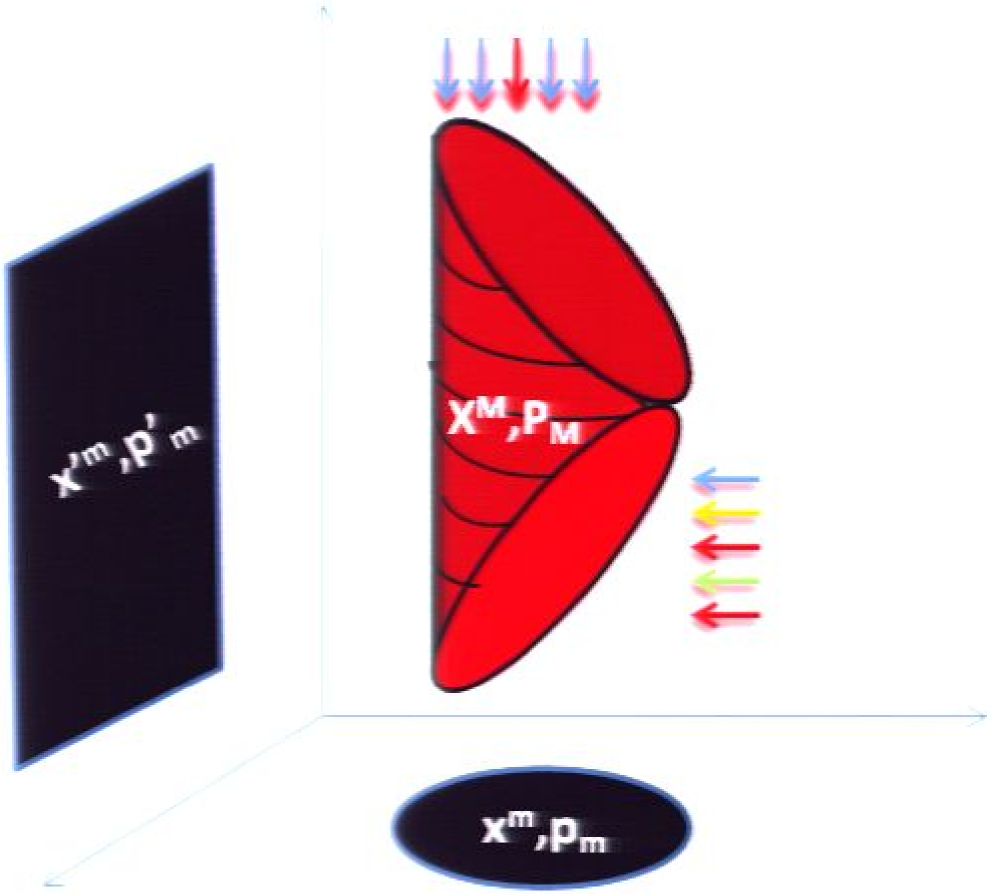

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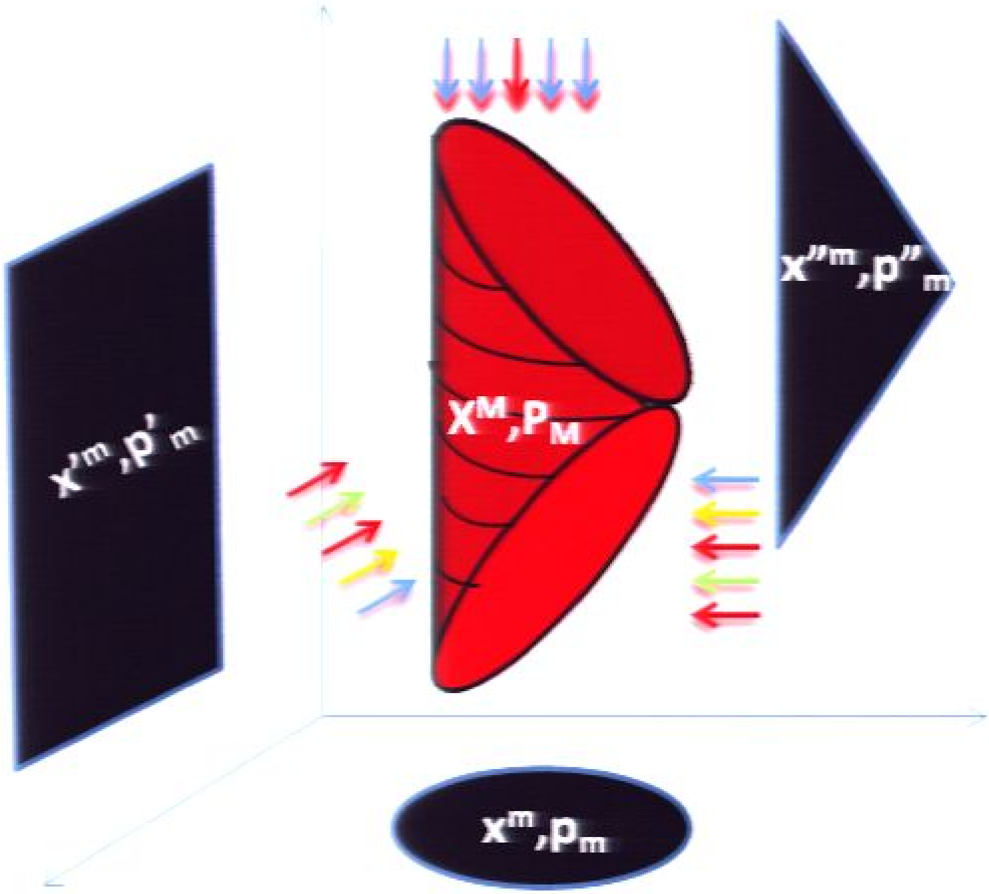

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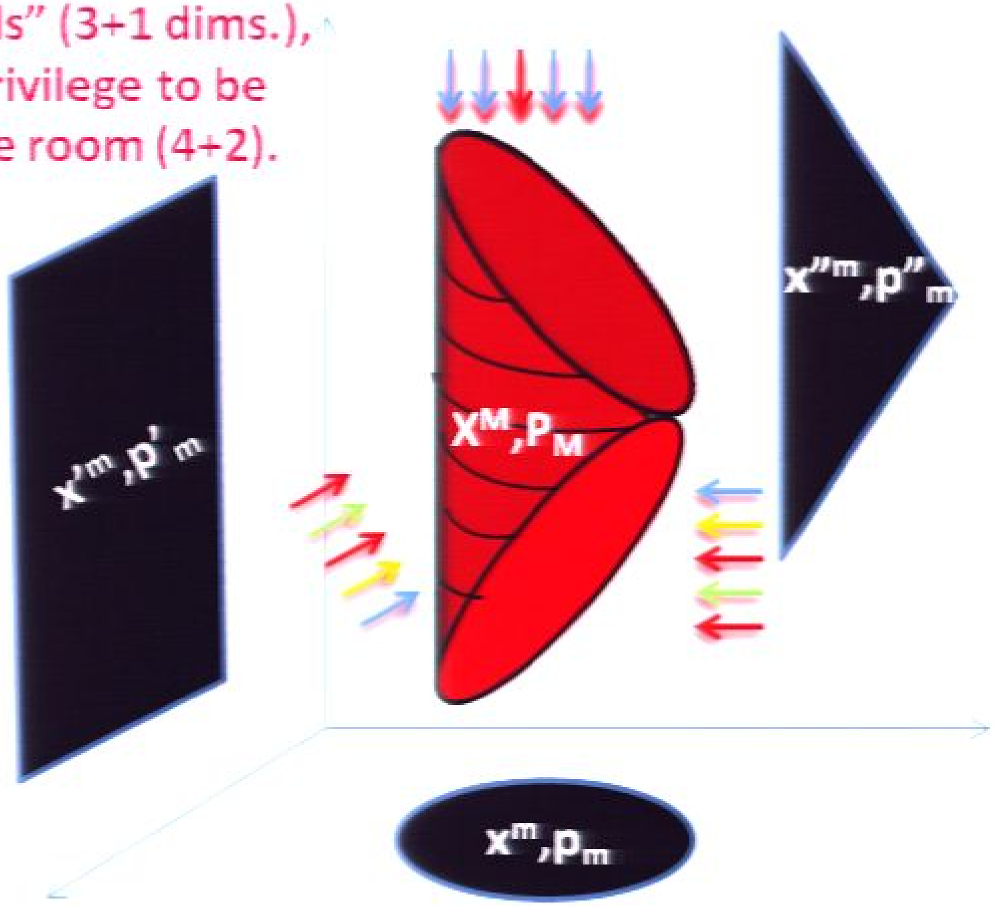

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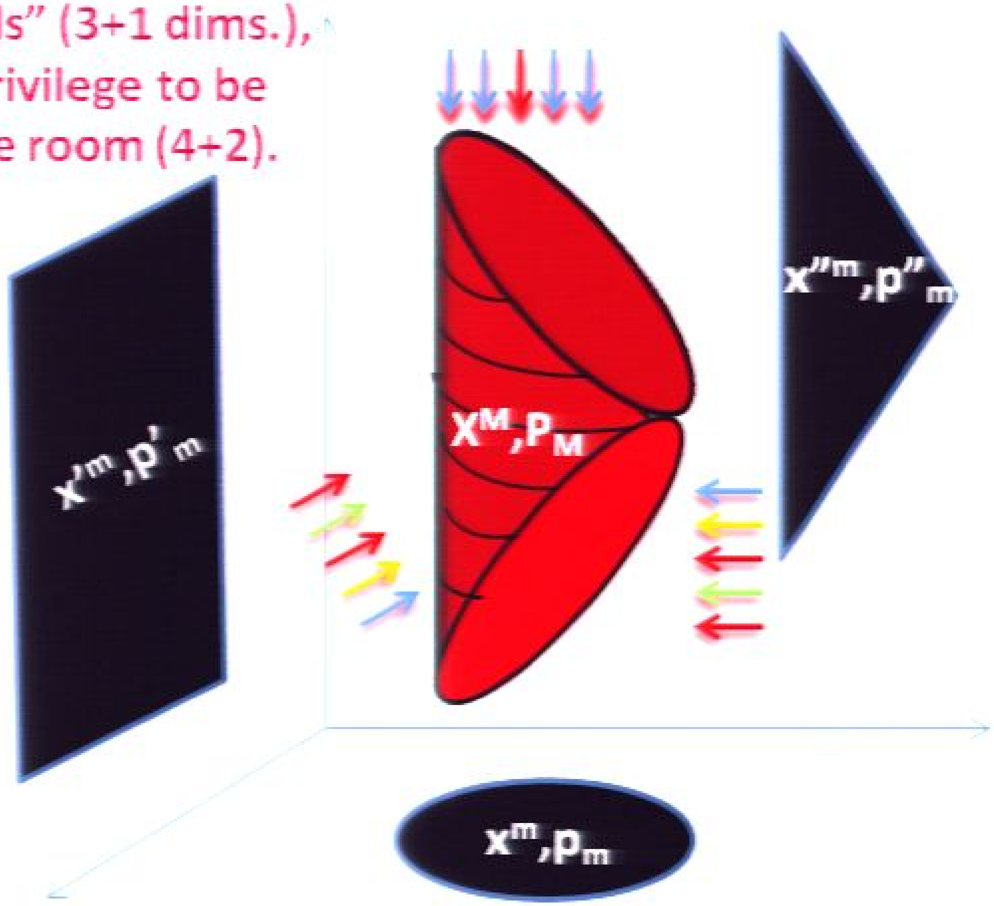

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Predict many relations among the shadows (dualities, symmetries d+2).

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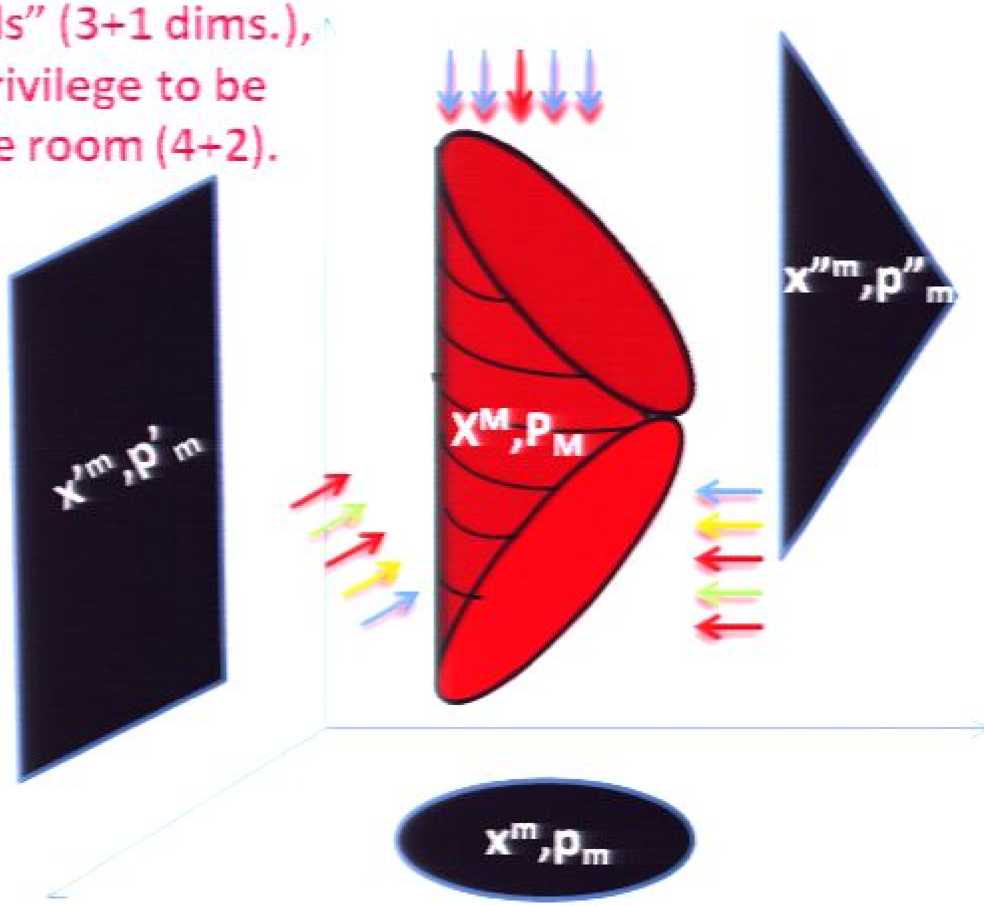

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This info related to higher spacetime:
Instead of interpreting the shadows as different dynamical systems (1T), must recognize they are perspectives in higher spacetime. Then, we can indirectly "see" the extra 1+1 dims.

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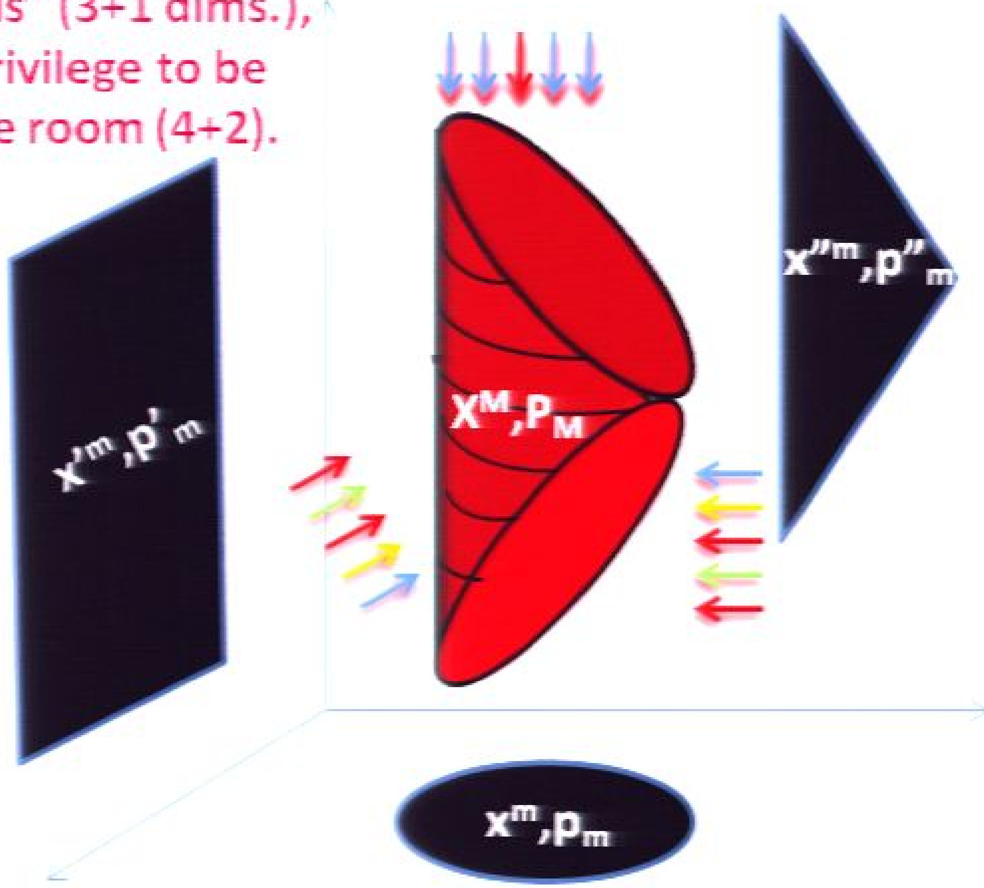

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1) 1T-physics is incomplete !!!
2) 2T-physics makes new testable predictions, and provides new computational tools

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Expect more predictions at every scale of distance or energy, and more powerful computational tools in future research ...

A quotation from Gell-Mann

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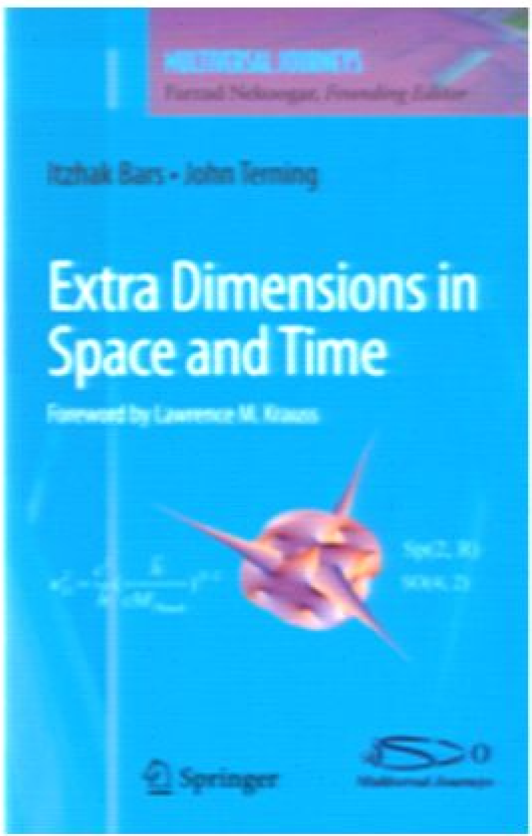
Anything which is not forbidden is compulsory!

Where to find more information on 2T-physics

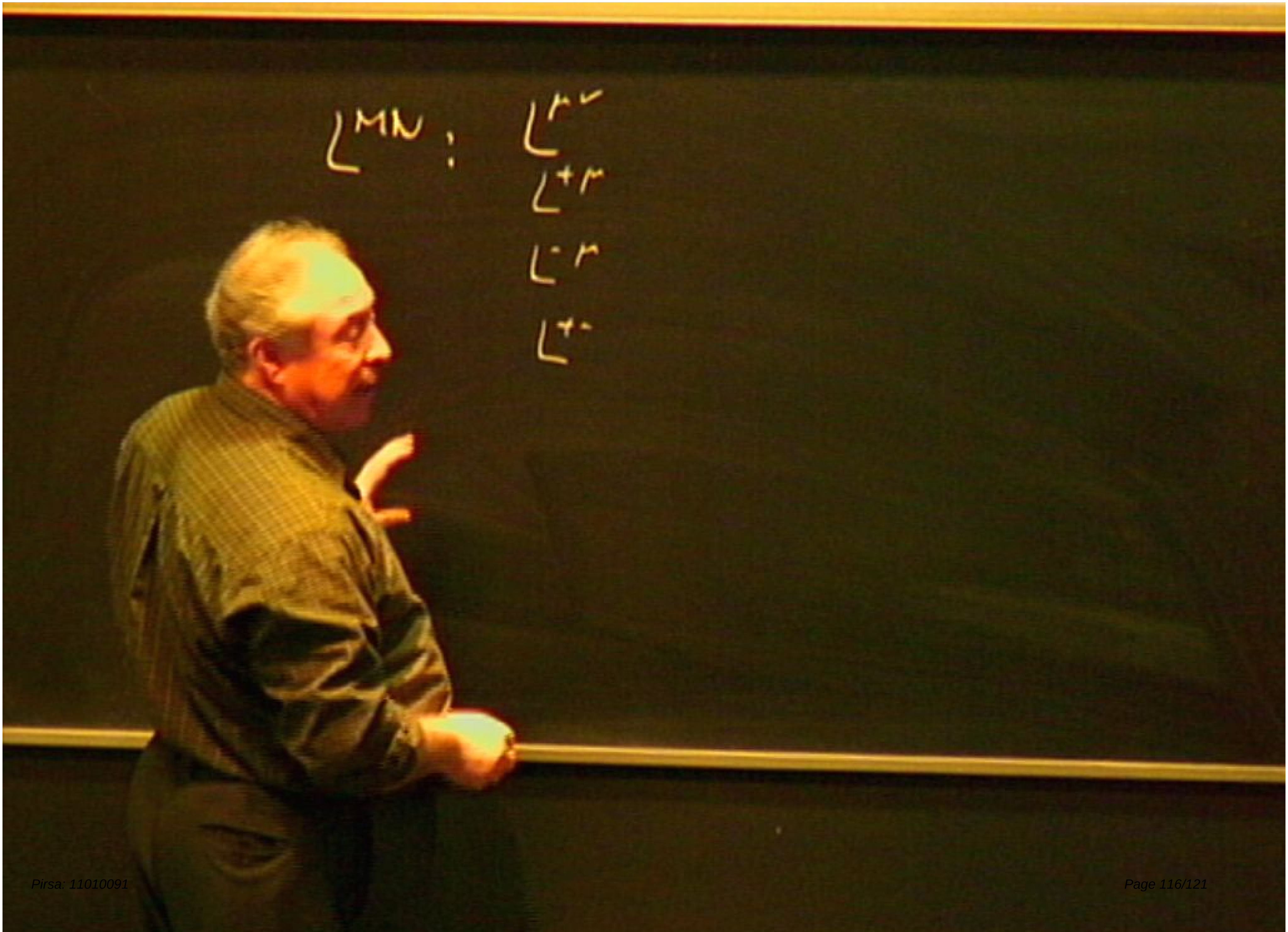
For concepts and technical guidance on over 50 papers
My recent talk: **arXiv:1004.0688**

A book at an elementary level for science enthusiasts (Springer 2009):



By
Itzhak Bars
and
John Terning

It can be downloaded at your university if your library has a contract with Springer (e.g. here at PI)
DOI: 10.1007/978-0-387-77638-5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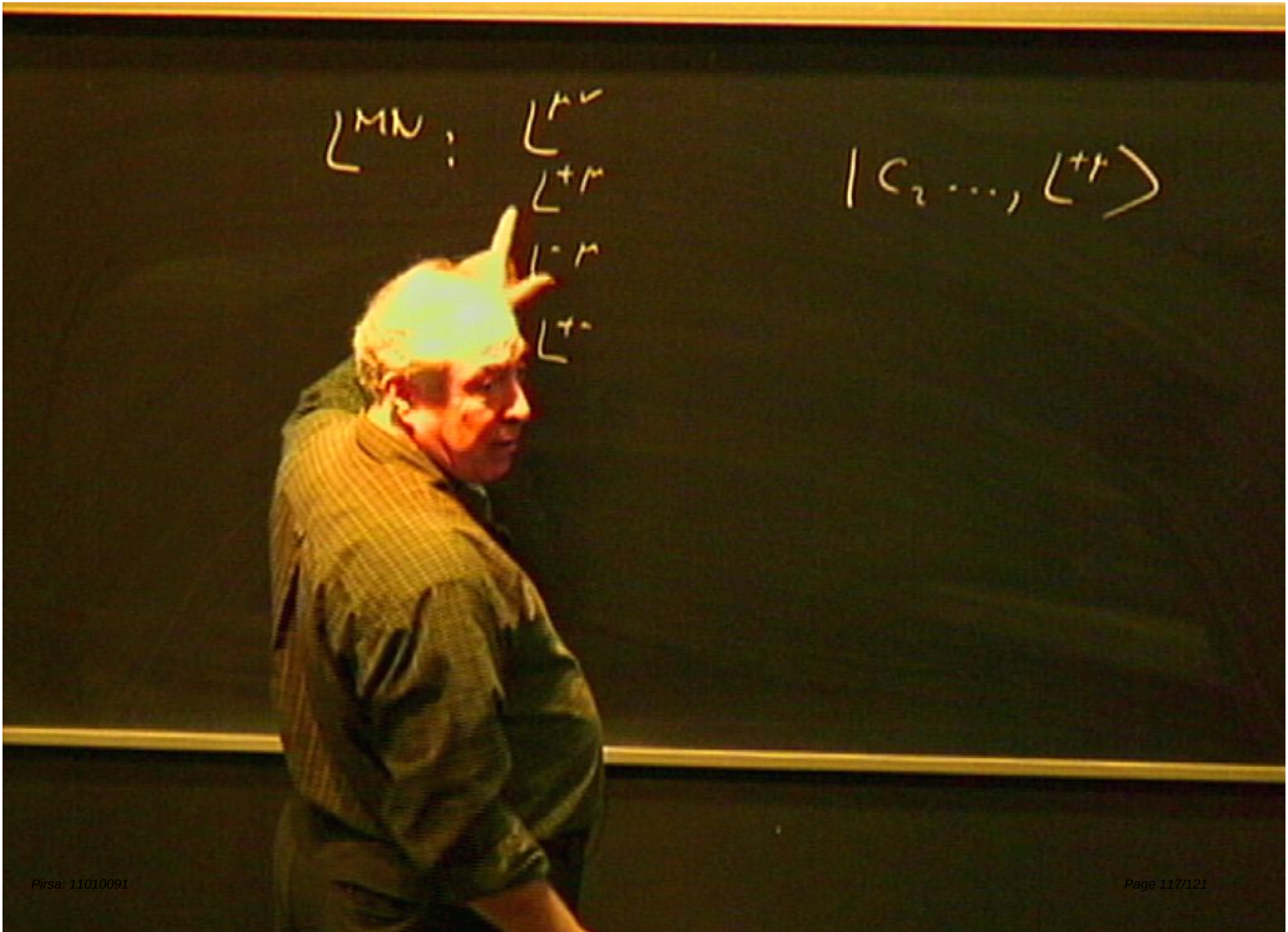
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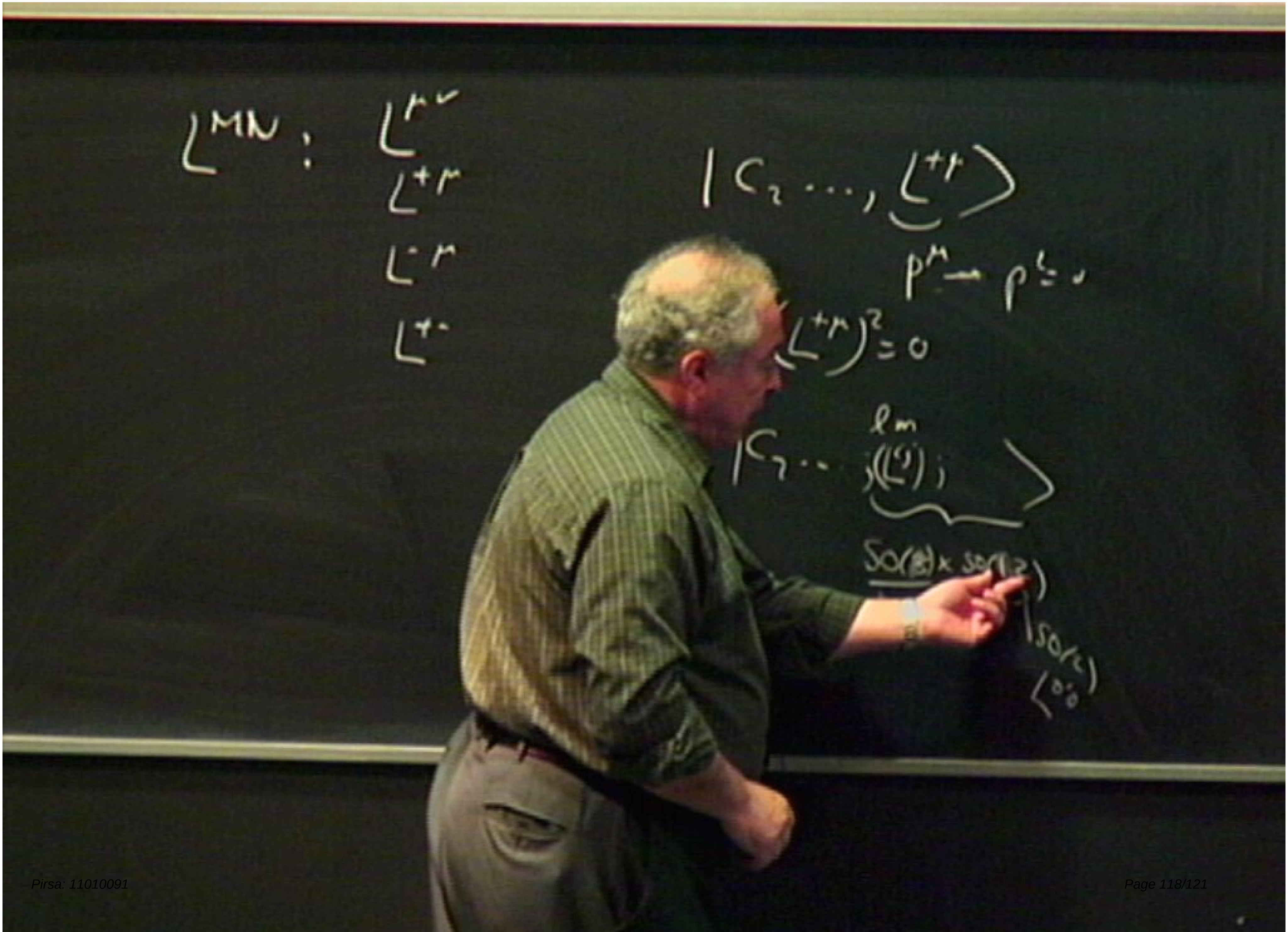
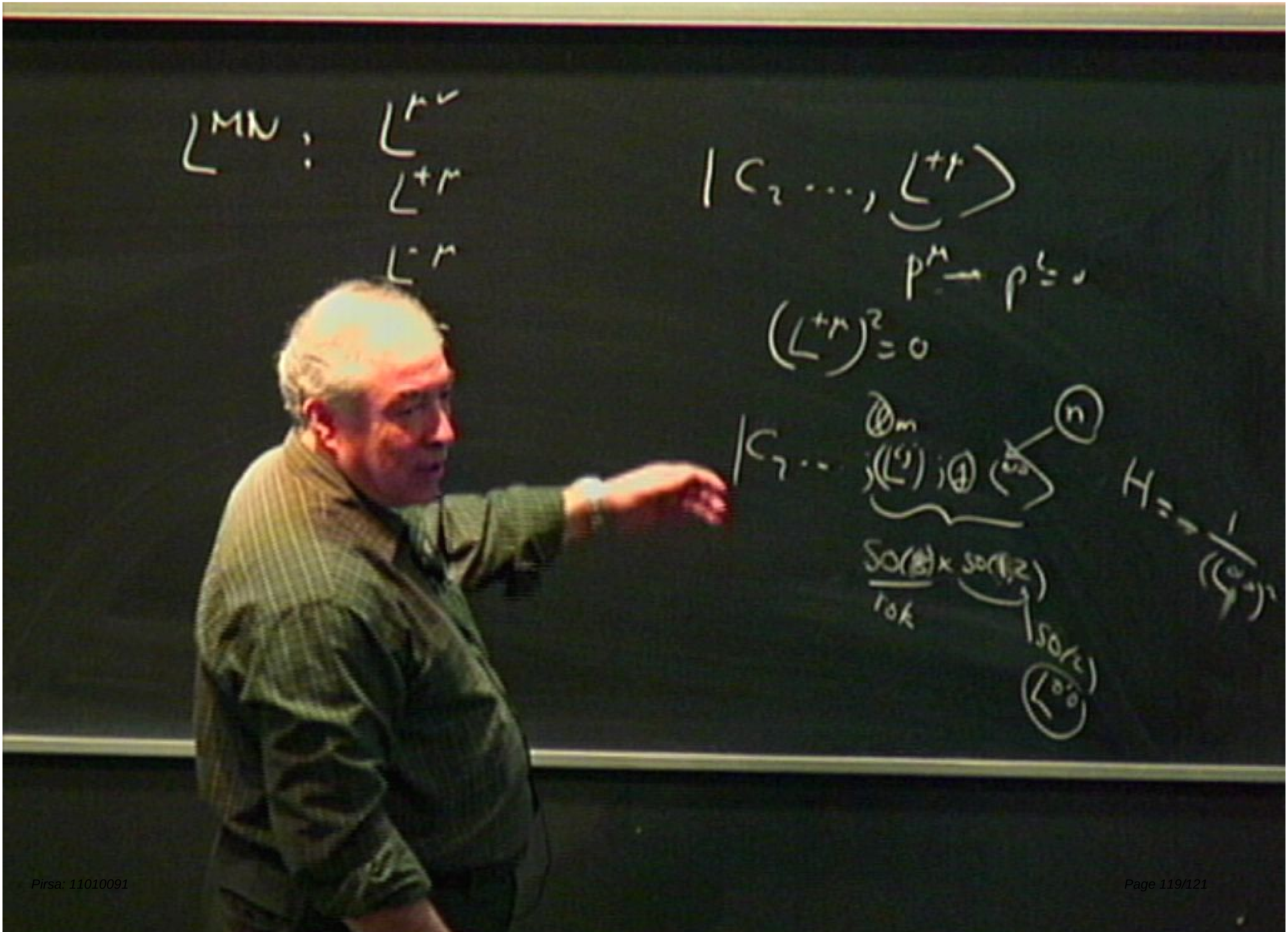
L^{+-}
$| c_2 \ldots, L^{+\mu} \rangle$




L^MN : L^μν
L^+μ
L^-μ
| C_2 ..., L^+μ >
p^μ → p^+ = 0
(L^+μ)^2 = 0
H =