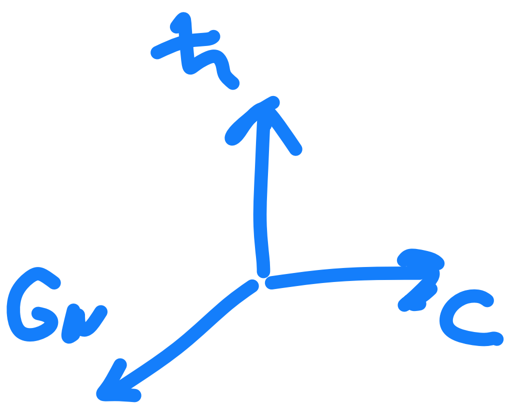
FROM QUANTUM MECHANICS TO QUANTUM SPACETIME AND BEYOND



$\leftrightarrow$ (TO QUANTUM GRAVITY)

$(\hbar c G_N)$

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OR

PARTICLES

METAPARTICLES

AND

QUANTUM GRAVITY

⊕ QUANTUM GRAVITY (QG) PHENOMENOLOGY 2111.05659

(IN THE INFARED)
(IR)

2104.00802

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(INFRARED ⟺ DARK ENERGY / DARK MATTER)

BASED ON: 2003.00318 (REVIEW) (FLM)

1) L. FREIDEL, R.G. LEIGH & D.M.

2) FLM + J. KOWALSKI-GLIKMAN

[1) → BORN GEOMETRY, MODULAR SPACETIME, METASTRING...
2) → METAPARTICLES]

3) D. EDMONDS, D.M., T. TAKEUCHI

2109.12763 [DARK MATTER]

4) P. BERGLUND, T. HÜBSCH, D.M.

2010.15610 [DARK ENERGY]

OTHER RELATED WORK DM ⊕

JEJJALA, KAVIC, TAKEUCHI 2202.05266

BERGLUND, HÜBSCH, MATTINGLY 2203.17137

HUBER, MINAKATA, PESTES, TAKEUCHI 2105.14061

TAKEUCHI, TZE 2012.06583

BARNES, HEREMANS 2111.10479

STOJKOVIC, DAI 2007.12184
⊕ KAVIC, SIMONETTI

(ALSO, WORK WITH AYDEMIR, SUN, TAKEUCHI)
NCG OF THE STANDARD MODEL

MAIN MESSAGE:

QUANTUM RELATIVITY

I) QUANTUM MECHANICS FROM QUANTUM SPACETIME

(BORN GEOMETRY, RELATIVE LOCALITY)

II) QFT → (METAPARTICLES) (METAFIELDS)

III) QUANTUM GRAVITY → (METASTRING) (DARK MATTER; DARK ENERGY) (DYNAMICAL QUANTUM SPACETIME)

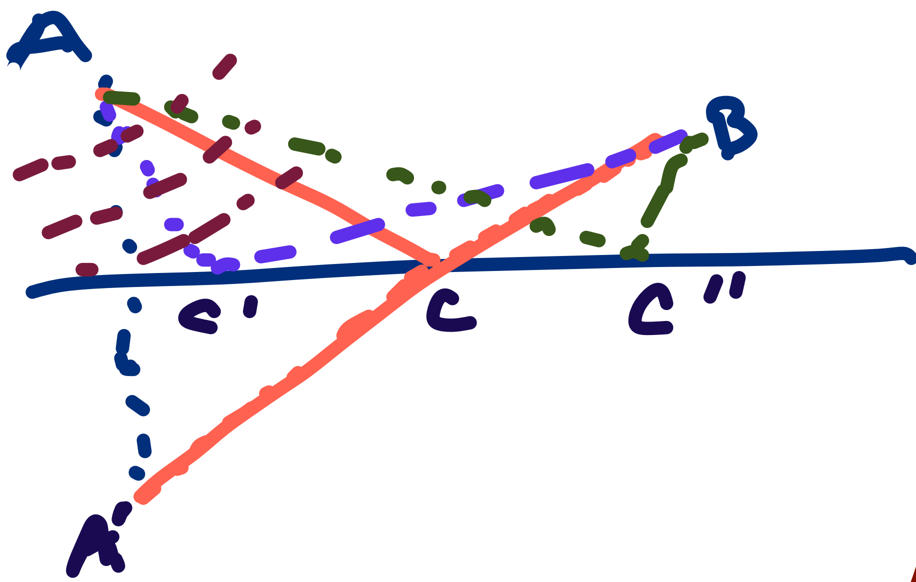
COMPARE TO CLASSICAL RELATIVITY:

a) SPECIAL RELATIVITY
(MINKOWSKI GEOMETRY
RELATIVE SIMULTANEITY)

b) CLASSICAL FIELD THEORY
(REPS. OF LORENTZ GROUP,
PARTICLES/ANTIPARTICLES)

c) GENERAL RELATIVITY
(DYNAMICAL SPACETIME)

QUANTUM MECHANICS



RAY $\longleftrightarrow$ "PARTICLE"

WAVE $\longleftrightarrow$ "WAVE"

EIKONAL $\quad I = \int \vec{k}\cdot d\hat{r} - \omega\, dt$

$\updownarrow$

ACTION $\quad S = \int p_i\, dq^i - H\, dt$

RAY : $\delta I = 0$ $\longleftrightarrow$ "PARTICLE" : $\delta S = 0$

WAVE : $\psi \sim e^{iI}$ $\longleftrightarrow$ "WAVE" : $\psi \sim e^{i\frac{S}{\hbar}}$

SCHRÖDINGER: $\quad \frac{\partial S}{\partial t} = -H$

$$\psi \sim e^{i\frac{S}{\hbar}} \rightarrow i\hbar \frac{\partial \psi}{\partial t} = H\psi \Longrightarrow \sum_{\text{paths}} \exp\left(i\frac{S}{\hbar}\right)$$

MAIN INSIGHT:

SUPPOSE WE DEFINE OUR PHYSICS ON A LATTICE (DISCRETE SPACETIME)

(THIS LATTICE/SPACETIME IS CLASSICAL, EVEN THOUGH OUR PHYSICS IS QUANTUM)

$$\int D\phi(x)\, e^{\frac{i}{\hbar}S[\phi(x)]} \longleftrightarrow \sum_n e^{\frac{i}{\hbar}S[\phi_n]}$$

CLASSICAL LABEL

LATTICE (e)

[RENORMALIZATION]

$\downarrow$

CONTINUUM LIMIT

MAIN INSIGHT (CONT.)

IN QUANTUM THEORY WE NEED A LATTICE (ℓ) AND ITS DUAL ($\hat{\ell}$) (ZAK)

$[\hat{q}, \hat{p}] = i\hbar$

$$\hat{U}_a \equiv \exp\left(\frac{i}{\hbar}\hat{p}\, a\right)$$

$$\hat{V}_a \equiv \exp\left(\frac{i}{\hbar}\hat{q}\,\frac{2\pi\hbar}{a}\right)$$

$$\boxed{[\hat{U}_a, \hat{V}_a] = 0}$$

$$\underset{\ell}{\uparrow} \qquad \underset{\tilde{\ell}}{\uparrow}$$

MAIN INSIGHT (CONT.)

DEFINE (AHARONOV)

$$[\hat{q}]_a \equiv \hat{q} \bmod (a)$$

$$[\hat{p}]_{\frac{2\pi\hbar}{a}} \equiv \hat{p} \bmod \left(\frac{2\pi\hbar}{a}\right)$$

$$\Downarrow$$

$$[\hat{q}, \hat{p}] = i\hbar \implies \left[[\hat{q}]_a, [\hat{p}]_{\frac{2\pi\hbar}{a}}\right] = 0$$

$[\hat{q}]_a$, $[\hat{p}]_{\frac{2\pi\hbar}{a}}$ – MODULAR VARIABLES

MAIN INSIGHT (CONT.)

MODULAR VARIABLES ARE NON-LOCAL (λ)

"FUNDAMENTAL LENGTH"

MODULAR VARIABLES ARE COVARIANT

$$\left[[\hat{x}^{\mu}]_{\lambda}, [\hat{p}_{\nu}]_{\epsilon} \right] = 0$$

$\hbar = \lambda \epsilon$ (MODULAR TIME MODULAR ENERGY ...)

EXPLICIT NON-LOCALITY:

$$H = \frac{p^2}{2m} + V(q) \qquad [e^{\frac{i}{\hbar}\hat{p}a}, \hat{H}]$$

$$\Rightarrow \frac{d\left(\exp\left(\frac{i}{\hbar}\hat{p}a\right)\right)}{dt} \sim \dots \overbrace{\frac{V(q+a)-V(q)}{a}} \dots$$

$$\Rightarrow \frac{d[\hat{p}]_R}{dt} = -\frac{V\left(q+\frac{R}{2}\right)-V\left(q-\frac{R}{2}\right)}{R}$$

(R – "CONTEXTUALITY PARAMETER)

R - DOUBLE SLIT EXPERIMENT (INTERFERENCE)

REFORMULATE QUANTUM THEORY

USING MODULAR VARIABLES

$\Rightarrow$ MODULAR SPACETIME

NOTE: $[\hat{q}, \hat{p}] = i\hbar$ WEYL-HEISENBERG ALGEBRA

BUT $[\hat{U}_a, \hat{V}_a] = 0$

COMMUTING SUBALGEBRA OF WEYL-HEISENBERG

$\Rightarrow$ MODULAR SPACETIME

OR SELF-DUAL LATTICE $(\ell \oplus \tilde{\ell})$

LIFTED TO WEYL-HEISENBERG (MACKEY)

MODULAR SPACETIME (IN D DIMENSIONS) → BORN GEOMETRY

$[\,,\,] \to$ SYMPLECTIC $\to \omega \; (Sp(2D))$

$\ell \oplus \hat{\ell} \to$ ORTHOGONAL (DOUBLY) $\to \eta \; (O(D,D))$

VACUUM → CONFORMAL (DOUBLE METRIC) $\to H(O(2,2(D-1)))$

Now

$$\underbrace{O(D-1,1)}_{\text{LORENTZ (CAUSALITY)}} = \underbrace{\omega \cap \eta \cap H}_{\text{BORN}}$$

QUANTUM MECHANICS =

NON-LOCALITY ⊕ CAUSALITY

(FUNDAMENTAL LENGTH/TIME

⊕ LORENTZ)

RELATIVE (OBSERVER DEPENDENT)

LOCALITY RECONCILES FUNDAMENT.

LENGTH WITH LORENTZ

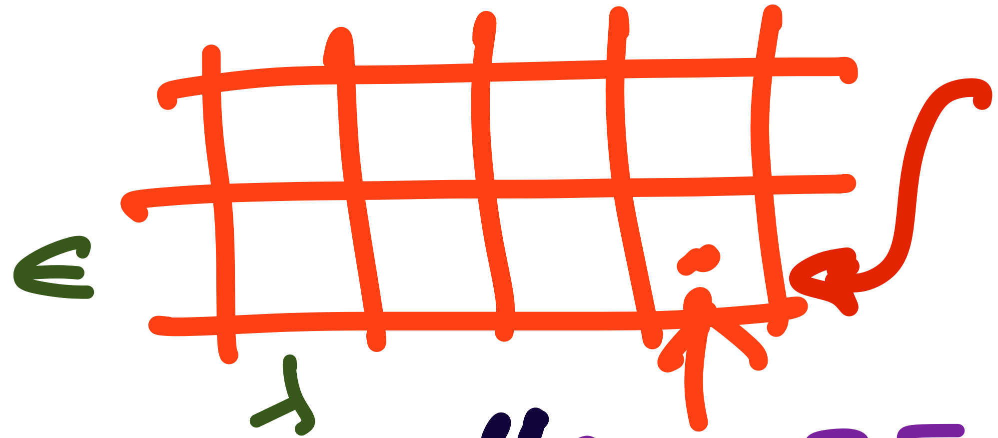
⇒ DIFFERENT OBSERVERS PROBE

DIFFERENT SPACETIMES

(DIFFERENT SLICES OF MODULAR SPACETIME)

DISCRETE (COVARIANT) PHASE SPACE

"BRILLOUIN CELL"



(COMMUTING MODULAR VARIABLES)

"CAN BE IN A PHASE SPACE CELL BUT CAN'T TELL IN WHICH ONE"

$\Rightarrow$ HEISENBERG UNCERTAINTY

MODULAR SPACETIME:

DISCRETE (COVARIANT) PHASE SPACE LIFTED TO WEYL-HEISENBERG ALGEBRA

ANALOGY WITH SPIN:

SPIN IS DISCRETE, BUT IT DOES NOT "BREAK" SO(3)

(DUE TO SUPERPOSITION PRINCIPLE)

MODULAR SPACETIME IS DISCRETE, BUT IT DOES NOT "BREAK" LORENTZ

(DUE TO SUPERPOSITION PRINCIPLE)

MODULAR POLARIZATION [ZAK TRANSFORM]

$$\Phi_\lambda(x,\tilde{x}) \equiv \sqrt{\lambda}\sum_m e^{-2\pi i m\tilde{x}}\, \underbrace{\psi_m(\lambda(x+m))}_{\text{SCHRÖDINGER}}$$

$$\left(x \equiv \frac{q}{\lambda},\quad \tilde{x} \equiv \frac{p}{\epsilon},\quad [x,\tilde{x}] = i,\quad \hbar \equiv \lambda\epsilon\right)$$

INVERSE ZAK TRANSFORM

$$\psi_m(x+m) = \int \frac{d\tilde{x}}{\sqrt{\lambda}}\, e^{2\pi i m\tilde{x}}\, \Phi_\lambda(\lambda^{-1}x, \tilde{x})$$

$$\left(\hat{\tilde{x}} \to -i\partial_x,\quad \hat{x} \to i\partial_{\tilde{x}} + x\right)$$

NOTE: FROM THE VIEWPOINT OF MODULAR SPACETIME

SCHRÖDINGER POLARIZATION IS VERY SINGULAR

SO USE $\mathbb{X}^A = \begin{pmatrix} x^a \\ \tilde{x}_b \end{pmatrix}$; $x^a = \frac{q^a}{\lambda}$, $\tilde{x}_b = \frac{p_b}{\epsilon}$

("AHARONOV–BOHM")

$W_{\mathbb{K}} \equiv \exp(2\pi i\, \omega(\mathbb{K}, \mathbb{X}))$

$\underline{Sp(2D)}$, $\omega(\mathbb{X}, \mathbb{Y}) \equiv \hat{x}\cdot y - x \cdot \hat{y}$

MODULAR VARIABLES

$\Rightarrow U_\lambda = \exp\left(i\frac{\pi}{2}\eta(\lambda,\lambda)\right) W_\lambda$

$\eta(\mathbb{P}, \mathbb{Q}) = \hat{p}\cdot q + \hat{q}\cdot p$

$\underline{O(D,D)}$

QUANTUM FIELD THEORY:

TAKE SCHRÖDINGER'S $\psi(x)$

SECOND QUANTIZE: $\psi(x) \to \hat{\psi}(x)$

QUANTUM FIELD ← OPERATOR

$$\int \mathcal{D}\phi(x)\, e^{\frac{i}{\hbar} S[\phi]}$$

($\phi(x)$ ← FIELD)

X – CLASSICAL SPACETIME

QUANTA OF QUANTUM FIELDS: PARTICLES (AND ANTIPARTICLES)

$$S_p = \int \Big[p\dot{x} - N\big(\underbrace{p^2 + m^2}\big)\Big]$$ ← PARTICLE ACTION

+ (PARTICLE)
– (ANTI-PARTICLE) ← $E = \pm\sqrt{\vec{p}^{\,2} + m^2}$

QFT: SECOND QUANTIZE

$\phi(x, \tilde{x}) \to \hat{\phi}(x, \tilde{x})$; $[x, \tilde{x}] = i\lambda^2$

ALSO, DOUBLE: (DOUBLE RG) ...

$\phi(x, \tilde{x})$ & $\tilde{\phi}(x, \tilde{x})$

(INTUITION: x & p
$\tilde{x}$ & $\tilde{p}$

BUT $p \to p + \phi$
$\tilde{p} \to \tilde{p} + \tilde{\phi}$ $\Leftarrow$ GAUGE SYMMETRY

FIRST PREDICTION:

METAPARTICLES (MP)

(QUANTA OF $\phi(x,\tilde{x})$ AND $\tilde{\phi}(x,\tilde{x})$)

$$S_{MP} = \int d\tau \Big[p\dot{x} + \tilde{p}\dot{\tilde{x}} - \overbrace{\lambda^2 p\dot{\tilde{p}}}^{\omega} - \frac{N}{2}\big(\underbrace{p^2+\tilde{p}^2}_{H}+m^2\big) - \tilde{N}\big(\underbrace{p\tilde{p}}_{\eta}-\mu\big)\Big]$$

$\tilde{p}\to 0,\ \mu\to 0$

ORDINARY PARTICLE

$$\left[\begin{array}{l} \text{PARTICLE} \to E \\ \text{DUAL PARTICLE} \to \dfrac{\mu}{E} \end{array}\right]$$

PATH INTEGRAL → PROPAGATOR

$$G(p, \hat{p}) \sim \frac{\delta(p\hat{p} - \mu)}{p^2 + \hat{p}^2 + m^2 - i\epsilon}$$

(CONSISTENT WITH UNITARITY AND CAUSALITY)

⇒ DISPERSION RELATION (IN A PARTICULAR GAUGE)

$$E_p^2 + \frac{\mu^2}{E_p^2} = \vec{p}^2 + m^2$$

(PHENO!)

IMPLICATIONS FOR NEUTRINO OSCILLATIONS

(DM TAKEUCHI)

$$P = \sqrt{E^2 - m^2 + \frac{\mu^2}{E^2}} \doteq E - \frac{m^2}{2E} - \frac{(m^4 - 4\mu^2)}{8E^3} + \cdots$$

PHASE DIFFERENCE

$$\phi_2 - \phi_1 = \frac{\delta m_{12}^2 L}{2E} + \boxed{\frac{(\delta m_{12}^4 - 4\,\delta \mu_{12}^4) L}{8E^3}} + \cdots$$

TOO SMALL TO MEASURE...?

$$\delta m_{12}^2 \equiv m_1^2 - m_2^2$$

$$\delta m_{12}^4 \equiv m_1^4 - m_2^4$$

$$\delta \mu_{12}^2 \equiv \mu_1^2 - \mu_2^2$$

CURVED BCKD: $ds^2 = g_{\mu\nu} dx^\mu dx^\nu + g^{\mu\nu} d\tilde{x}_\mu d\tilde{x}_\nu$

(COSMOLOGY)

$d\tilde{s}^2 = dx^\mu d\tilde{x}_\mu$

$$\Rightarrow a^{-2} p^2 + a^2 \tilde{p}^2 = \underline{m}^2$$

$\left(g_{\mu\nu} dx^\mu dx^\nu = -dt^2 + a^2 d\vec{x}^2 \right)$

LET $p = (E, \vec{p})$

$\tilde{p} = (\tilde{E}, \tilde{p})$

$$\Rightarrow E^2 - a^{-2} \vec{p}^2 + \tilde{E}^2 - a^2 \tilde{p}^2 = \underline{m}^2$$

$$E\tilde{E} + p\tilde{p} = \mu$$

3 LORENTZ INVARIANTS (NEW REPRESENTATION THEORY)

1) $p^2 + \tilde{p}^2$

2) $p \cdot \tilde{p}$ $\Rightarrow$

3) $\tilde{p}^2 - p^2$

USUAL MASS $m^2 \equiv -p^2 = (\underline{m}^2 + \delta)$

REPRESENTATION THEORY

I: $\underline{m}^2 > \mu$ II: $\mu > \underline{m}^2 \geq 0$

THUS: $a \to 0$, $\tilde{p} \neq 0$ EARLY

$a \to \infty$, $\tilde{p} \to 0$ LATE (UNIVERSE)

$\Rightarrow \underline{P} = (E, \underline{\vec{P}})$, $\underline{\vec{P}} = a\vec{p}$ μ – IR SCALE

$$E^2 + \frac{\mu^2}{E^2} - \underline{P}^2 = \underline{m}^2$$

"SEE-SAW" BETWEEN VISIBLE (p) & DARK MATTER ($\tilde{p}$)

PHENOMENOLOGY:

CLASS I: $\mu < \underline{m}^2$; (μ-IR SCALE)

APPLY TO NEUTRINOS ($\underline{\nu}$)

$$\sum_i m_i^{\nu} = 0.097\,\mathrm{eV}$$

$$\mu_\nu \leq 10^{-2}\,\mathrm{eV}^2 \iff$$ CLOSE TO DARK ENERGY SCALE

μ_ν FOR NEUTRINOS

(DIFFERENT SM PARTICLES: DIFFERENT μ's)

$\Rightarrow$ DUAL (DARK) SM ($\widetilde{SM}$)

ALSO, STATIC POTENTIAL (3+1)
(TO APPEAR)

$$r_+ = r + \tilde{r} \quad , \quad r_- = r - \tilde{r}$$

$$V(r_+, r_-) \sim \cos(\lambda^2 \mu_\pi) \frac{e^{-M_- r_-}}{r_-} \frac{\sin(M_+ r_+)}{r_+}$$

INTEGRATE OVER r_+ $(\lambda = 0)$

$$V(r_-) \sim \alpha \frac{e^{-\tilde{m} r_-}}{r_-}$$

(PHENO!)

$\tilde{m}(\mu)$

$\alpha(\mu)$

IN d SPACETIME DIMENSIONS

$$\delta V \sim \left(\sqrt{\mu}\right)^{\frac{d-1}{2}-1} \frac{1}{r^{d-1}} e^{-\sqrt{\mu}\, r} \sin\left(\sqrt{m^2-2\mu}\, r\right)$$

CORRECTION TO THE YUKAWA POTENTIAL

(AND SMALLER THAN THE LEADING QUANTUM CORRECTION)

QUASI-METAPARTICLE

(NON-FERMI LIQUID)

$$G_{MP}(E) \sim \frac{1}{\mu_R\sqrt{E-E_F} + (E-E_F) - i\epsilon}$$

ARPES DATA ON STRANGE METALS

$$\mu_R \sim (1.4 \pm 0.2)\sqrt{E_F}$$

E_F – FERMI ENERGY

(CMP & NUCLEAR NON-FERMI LIQUIDS)

QFT AND METAPARTICLES

TAKE
$$S_{MP} = \int d\sigma \Big[p\dot{x} + \tilde{p}\dot{\tilde{x}} - \lambda^2 p\dot{\tilde{p}} - \frac{N}{2}\left(p^2 + \tilde{p}^2 + m^2\right) - \tilde{N}\left(p\tilde{p} - \mu\right) \Big]$$

AND
$$p_\mu \to p_\mu + A_\mu$$
$$\tilde{p}_\mu \to \tilde{p}_\mu + \tilde{A}_\mu$$

$\Leftarrow$ DOUBLE GAUGE SYMMETRY

$$\Rightarrow S_{eff} \sim \int \left(F^2 + \tilde{F}^2 + \dots \underbrace{- \lambda^2 A_\mu \dot{\tilde{A}}_\mu}_{} + \dots\right)$$

FROM $-\lambda^2 p\dot{\tilde{p}}$

BERRY-PHASE-LIKE

META(PARTICLE) FIELDS

SCALARS $\phi, \tilde{\phi}$

$$S_\phi \sim \int (\partial\phi)^2 + (\partial\tilde{\phi})^2 + \frac{\lambda^\alpha}{L^\beta}\int d\sigma'\,\phi(x(\sigma'))\,\frac{d\phi(x(\sigma'))}{d\sigma'}$$

FERMIONS $\psi, \tilde{\psi}$

$$S_\psi \sim \int (\bar{\psi}\,\partial\psi) + (\bar{\tilde{\psi}}\,\partial\tilde{\psi}) + \frac{\lambda^\gamma}{L^\beta}\int d\sigma'\,\psi\,\frac{d\tilde{\psi}}{d\sigma'}$$

$\underbrace{\text{NEUTRINOS } (\psi) \text{ \& DUAL NEUTRINOS } (\tilde{\psi})}_{\text{METANEUTRINOS}}$

("RIGID STRINGS")

QUANTUM GRAVITY ⟵ DYNAMICAL BORN GEOMETRY

"GRAVITIZE THE QUANTUM"

$$S_{MS} = \int d\tau\, d\sigma \left[\partial_\tau \mathbb{X}^A \partial_\sigma \mathbb{X}^B (\omega_{AB} + \eta_{AB}) - \partial_\sigma \mathbb{X}^A \partial_\sigma \mathbb{X}^B H_{AB} \right]$$

NOTE, IN GENERAL:

$\omega_{AB}(\mathbb{X})$, $\eta_{AB}(\mathbb{X})$, $H_{AB}(\mathbb{X})$

$\Rightarrow$ METASTRING (BOSONIC CHIRAL NON-COMMUTATIVE...)

$\left(\alpha' = \frac{\lambda}{\epsilon} \leftarrow \text{STRING TENSION} \right)$

QUANTUM GRAVITY (CONT.)

$$[\mathbb{X}^A, \mathbb{X}^B] = i\,\omega^{AB} \quad \| \quad [x, \tilde{x}] = i\lambda^2$$

ZERO MODES OF THE METASTRING

$\Rightarrow$ METAPARTICLE (S_{MP})

BACKGROUND SPACETIME

$\Rightarrow$ MODULAR SPACETIME

OBSERVABLES: MODULAR VARIABLES

$\Rightarrow \exp(i\,\mathbb{K}\cdot\mathbb{X})$ REPS OF WEYL-HEISENBERG

EFFECTIVE NON-COMMUTATIVITY

EXPLICIT RELATIVE LOCALITY!

$$\tilde{x}_a \to \tilde{x}_a + B_{ab} x^b$$

$$\Rightarrow \quad [x^a, x^b] = 0$$

$$[x^a, \tilde{x}_b] = 2\pi i \lambda^2 \delta^a_b$$

$$[\tilde{x}_a, \tilde{x}_b] = -4\pi i \lambda^2 B_{ab}$$

$B_{ab} = -B_{ba}$ (B - BCKD OF STRING THEORY)

$\updownarrow$

ω_{ab} IN 4D: B DUAL TO AXIONS

NEW NC: RELATIVE LOCALITY

$$X^a \to X^a + \beta^{ab}\tilde{X}_b$$

$$\Rightarrow \underbrace{[X^a, X^b] = 4\pi i \lambda^2 \beta^{ab}}_{\text{SPACETIME NON-COMMUTATIVITY}} \quad (NC)$$

$$[X^a, \tilde{X}_b] = 2\pi i \lambda^2 \delta^a{}_b$$

(PHENO BOUND: 10 TeV)

$$[\tilde{X}_a, \tilde{X}_b] = 0$$

IN PRINCIPLE, FOR VARYING β:

$$[X^a,[X^b, X^c]] + \text{cyclic} = \ell^{abc}$$

NON-ASSOCIATIVITY (e.g. OCTONIONS & THE STANDARD MODEL)

& NON-COMMUTATIVITY → THE STANDARD MODEL

QUANTUM GRAVITY (CONT.)

BUILD SPACETIME FROM MODULAR CELLS $\boxed{\cdot}$ ("EXTENSIFICATION")

(1D MODULAR SPACETIME)

→ 2D TORUS

NON-PERTURBATIVE QUANTUM GRAVITY

($\tau, \sigma \to$ MODULAR WORLD-SHEET)

$\mathbb{X} \to \hat{\mathbb{X}}$ (MATRICES) $\partial_\sigma \hat{\mathbb{X}} = [\mathbb{Y}, \mathbb{X}]$

MATRIX QUANTUM THEORY:

$$\hat{S} = \int d\tau \left(\partial_\sigma \mathbb{X}^a [\mathbb{X}^b, \mathbb{X}^c] \eta_{abc} - [\mathbb{X}^a, \mathbb{X}^b][\mathbb{X}^c, \mathbb{X}^d] \eta_{abcd} \right)$$

DARK MATTER AND DARK ENERGY

GR: $R_{\mu\nu} - \frac{1}{2} g_{\mu\nu} R - \lambda g_{\mu\nu} = 8\pi G_N T_{\mu\nu}$

$\frac{\lambda}{G_N} \longleftrightarrow$ DARK ENERGY

(λ – COSMOLOGICAL CONSTANT)

$T_{\mu\nu} \longleftrightarrow T_{\mu\nu}^{(\text{VISIBLE})} + T_{\mu\nu}^{(\text{DARK})}$

VISIBLE MATTER: STANDARD MODEL (SM) OF PARTICLE PHYSICS

DARK MATTER: NOT IN SM

DARK MATTER (LEADING ORDER IN λ^2)

$$S_{eff} \sim -\int \sqrt{g(x)\,\tilde{g}(\tilde{x})}\left[\mathcal{L}_m(x,\tilde{x}) + \tilde{\mathcal{L}}_{DM}(x,\tilde{x}) + \dots\right]$$

WHERE $\mathcal{L}_m(x,\tilde{x}) = \mathcal{L}_m(\phi(x,\tilde{x}))$

$\tilde{\mathcal{L}}_{DM}(x,\tilde{x}) = \tilde{\mathcal{L}}_{DM}(\tilde{\phi}(x,\tilde{x}))$

INTEGRATE OVER DUAL SPACETIME ($\tilde{x}$)

$$S_{eff} \sim -\int \sqrt{-g(x)}\left(\mathcal{L}_m(x) + \underline{\tilde{\mathcal{L}}_{DM}(x)} + \dots\right)$$

STANDARD MODEL

PARTICLE & DUAL PARTICLE $\Leftarrow \|$

DUAL STANDARD MODEL

DARK MATTER PHENO:

DARK MATTER CORRELATED TO VISIBLE MATTER

(AND DARK ENERGY (Λ))

DATA FROM GALAXIES ALSO FROM CLUSTERS

$a_{observed}$ CORRELATED TO $a_{BARYONIC}$

VIA A UNIVERSAL ACCELERATION

$$a_0 \sim \frac{cH}{2\pi} \sim 10^{-10} \frac{m}{s^2}$$

$$\Lambda \sim \frac{1}{H^2}$$

DARK ENERGY (LEADING ORDER IN λ^2)

$$S_{eff} \sim - \int \sqrt{g(x)\,\tilde{g}(\tilde{x})}\left[R(x) + \tilde{R}(\tilde{x}) + \ldots\right]$$

INTEGRATE OVER DUAL SPACETIME ($\tilde{x}$)

$$S_{eff} \sim - \underbrace{\boxed{\int \sqrt{-\tilde{g}(\tilde{x})}}}_{G_N^{-1}} \int \sqrt{-g(x)}\, R(x)$$

$$- \underbrace{\boxed{\int \sqrt{-\tilde{g}(\tilde{x})}\,\tilde{R}(\tilde{x})}}_{G_N^{-1}\Lambda} \int \sqrt{-g(x)}$$

COSMOLOGICAL CONSTANT (DARK ENERGY)

DARK ENERGY PHENO:

NOTE $\bar{S} \sim \tilde{V} \int \sqrt{-g}\,(R + \mathcal{L})$

BUT $V\tilde{V} \sim \Lambda$

$$\bar{S} \sim \frac{\int \sqrt{-g}\,(R+\mathcal{L})}{\int \sqrt{-g}}$$

"SEE-SAW" FORMULA $(\bar{S} \sim \Lambda)$

$$M_\Lambda \sim \frac{M^2}{M_P} \leftrightarrow (G_N^{-1} \Lambda)$$

IF $M \sim 1\,\mathrm{TeV}$ $(M_P \sim 10^{19}\,\mathrm{GeV})$

$\Rightarrow M_\Lambda \sim 10^{-3}\,\mathrm{eV}$ (ALSO, RADIATIVE STABILITY)

VIA SEQUESTER

CC NATURALLY SMALL:

VACUUM ENERGY $\int^{\Lambda_{cc}} d^3k\sqrt{E^2+k^2} \sim \Lambda_{cc}^4 \sim \left(\frac{\mu}{\tilde{\Lambda}_{cc}}\right)^4$

$\uparrow$

$\left(\int \frac{d^4p}{(2\pi)^4}\right)$

(COMPARE TO $M_\lambda = \frac{m^2}{M_p}$!)

IN GENERAL, DYNAMICAL CC

(H$_0$ TENSION)

STATISTICAL EFFECTS OF QUANTUM GRAVITY

(INFINITE STATISTICS)

ALSO, NEW APPROACH TO VACUUM SELECTION

(UNIVERSAL COSMOLOGY)

COSMOLOGY

$M = E_{IR} E_{UV}$ UV/IR MIXING

$\Rightarrow \quad w_{eff} \leq -1$ FOR DARK ENERGY

($w_{eff} = -1$ — COSMOLOGICAL CONSTANT)

$\Rightarrow$ ~~ACCELERATED~~ ACCELERATED EXPANSION ($w_{eff} < -1$)

(H_0 TENSION)

$\Rightarrow$ ASTROPHYSICS (NEUTRON STARS BLACK HOLES...)

GRAVITIZING THE QUANTUM

1) MULTI-PATH INTERFERENCE

QM: $P_2(A,B) = |\psi_A + \psi_B|^2 = P_1(A) + P_2(B) + I_2(A,B)$

BUT $I_3(A,B,C) = 0$

$I_3(A,B,C) = P_3(A,B,C) - P_2(A,B) - P_2(A,C) - P_2(B,C)$
$+ P_1(A) + P_1(B) + P_1(C)$

PHOTON PROBES $\dfrac{I_3}{\sum |I_2|} < 10^{-3}$

NEUTRINO PROBES (JUNO) ALSO $< 10^{-3}$ (!)

(GQ) GRAVITIZING THE QUANTUM

IN QUANTUM GRAVITY (QG = GQ)

$I_3 \neq 0$ PHOTONIC (OR NEUTRINO) EXPERIMENT IN VARYING GRAV. FIELD

$\Rightarrow$ BORN RULE DYNAMICAL

OTHER IMPLICATIONS?

(NOTE: IN GENERAL $I_3 \neq 0, I_4 \neq 0 \ldots$ ETC)

GRAVITIZING THE QUANTUM

$\Rightarrow$ DYNAMICAL BORN RULE

IN QM: $2\hbar\, ds_{FS} = \Delta E\, dt$

BORN RULE $\equiv$ FUBINI-STUDY METRIC OF CP^N

OPTICAL LATTICE ATOMIC CLOCKS

$$\frac{\Delta\nu}{\nu} = (1+\alpha)\frac{\Delta U}{c^2}$$

$\alpha = 0$ REDSHIFT

$\alpha < 10^{-5}$

$\Rightarrow$ BOUND ON DYNAMICAL ds

SUMMARY:

I) QUANTUM MECHANICS VIA QUANTUM/MODULAR SPACETIME

(BORN GEOMETRY)

II) QFT (METAPARTICLES DOUBLED FIELDS)

III) QUANTUM GRAVITY (QG)

(DYNAMICAL BORN GEOMETRY)

(DARK MATTER, DARK ENERGY)

PHENOMENOLOGY: (QG PHENO IN THE IR)

DEFORMED DISPERSION RELATION

DEFORMED STATIC POTENTIAL

DARK MATTER CORRELATED TO VISIBLE MATTER AND DARK ENERGY

METAPARTICLES, METASTRINGS

"DARK ENERGY SEE-SAW"

GRAVITIZING THE QUANTUM