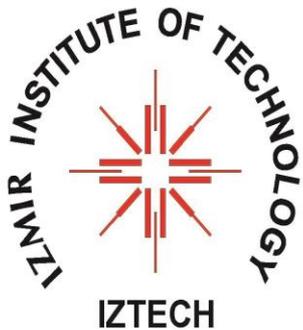


GRAVITIZATION

OF EFFECTIVE FIELD THEORY AND ULTRAVIOLET STABILITY

Durmuş Demir

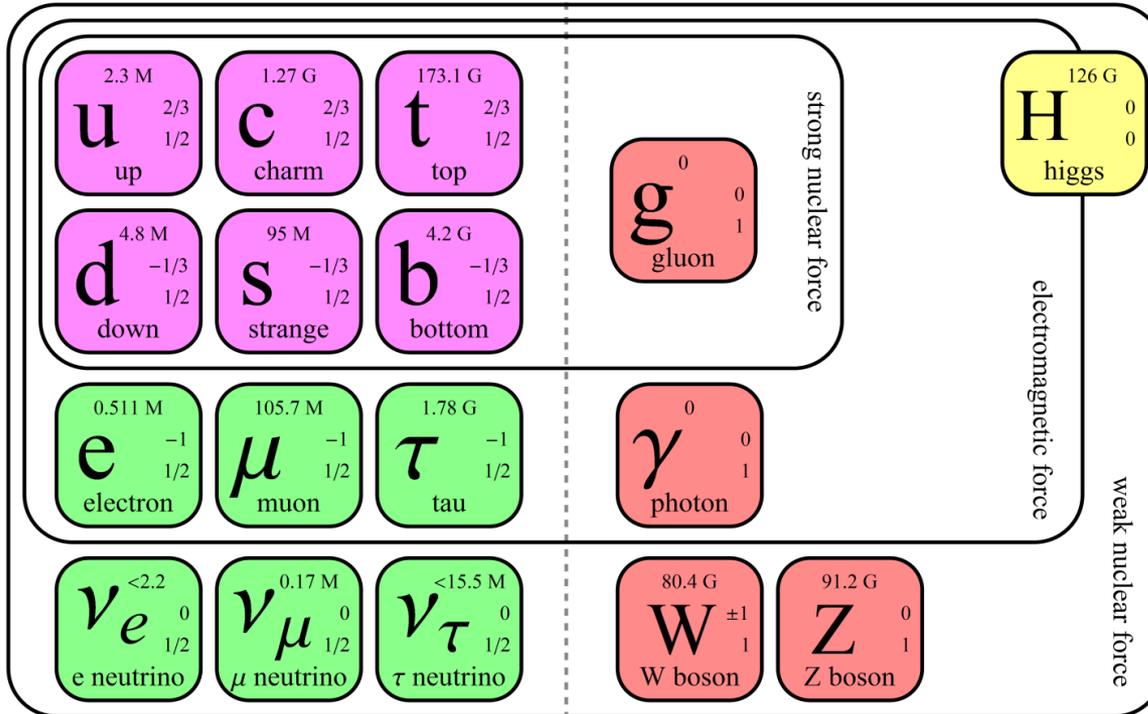


NKP MEMORIAL SYMPOSIUM

November 10, 2016

the Standard Model

fully confirmed
by **experiments**



does not
include
gravity

quantum field theory
of the Electromagnetic, Weak
and Strong interactions.

the SM continues to hold at high energies

ATLAS Exotics Searches* - 95% CL Exclusion

Status: August 2016

ATLAS Preliminary

$$\int \mathcal{L} dt = (3.2 - 20.3) \text{ fb}^{-1}$$

$$\sqrt{s} = 8, 13 \text{ TeV}$$

Model	ℓ, γ	Jets [†]	$E_{\text{T}}^{\text{miss}}$	$\int \mathcal{L} dt [\text{fb}^{-1}]$	Limit	Reference	
Extra dimensions	ADD $G_{KK} + g/q$	-	$\geq 1 j$	Yes	3.2	M_D 6.58 TeV	$n = 2$ 1604.07773
	ADD non-resonant $\ell\ell$	$2 e, \mu$	-	-	20.3	M_S 4.7 TeV	$n = 3 \text{ HLZ}$ 1407.2410
	ADD QBH $\rightarrow \ell q$	$1 e, \mu$	$1 j$	-	20.3	M_{th} 5.2 TeV	$n = 6$ 1311.2006
	ADD QBH	-	$2 j$	-	15.7	M_{th} 8.7 TeV	$n = 6$ ATLAS-CONF-2016-069
	ADD BH high Σp_T	$\geq 1 e, \mu$	$\geq 2 j$	-	3.2	M_{th} 8.2 TeV	$n = 6, M_D = 3 \text{ TeV, rot BH}$ 1606.02265
	ADD BH multijet	-	$\geq 3 j$	-	3.6	M_{th} 9.55 TeV	$n = 6, M_D = 3 \text{ TeV, rot BH}$ 1512.02586
	RS1 $G_{KK} \rightarrow \ell\ell$	$2 e, \mu$	-	-	20.3	$G_{KK} \text{ mass}$ 2.68 TeV	$k/\bar{M}_{Pl} = 0.1$ 1405.4123
	RS1 $G_{KK} \rightarrow \gamma\gamma$	2γ	-	-	3.2	$G_{KK} \text{ mass}$ 3.2 TeV	$k/\bar{M}_{Pl} = 0.1$ 1606.03833
	Bulk RS $G_{KK} \rightarrow WW \rightarrow qq\ell\nu$	$1 e, \mu$	$1 J$	Yes	13.2	$G_{KK} \text{ mass}$ 1.24 TeV	$k/\bar{M}_{Pl} = 1.0$ ATLAS-CONF-2016-062
	Bulk RS $G_{KK} \rightarrow HH \rightarrow bbbb$	-	$4 b$	-	13.3	$G_{KK} \text{ mass}$ 360-860 GeV	$k/\bar{M}_{Pl} = 1.0$ ATLAS-CONF-2016-049
Bulk RS $G_{KK} \rightarrow tt$	$1 e, \mu$	$\geq 1 b, \geq 1 J/2 j$	Yes	20.3	$G_{KK} \text{ mass}$ 2.2 TeV	BR = 0.925 1505.07018	
2UED / RPP	$1 e, \mu$	$\geq 2 b, \geq 4 j$	Yes	3.2	$KK \text{ mass}$ 1.46 TeV	Tier (1,1), BR($A^{(1,1)} \rightarrow tt$) = 1 ATLAS-CONF-2016-013	
Gauge bosons	SSM $Z' \rightarrow \ell\ell$	$2 e, \mu$	-	-	13.3	$Z' \text{ mass}$ 4.05 TeV	ATLAS-CONF-2016-045
	SSM $Z' \rightarrow \tau\tau$	2τ	-	-	19.5	$Z' \text{ mass}$ 2.02 TeV	1502.07177
	Leptophobic $Z' \rightarrow bb$	-	$2 b$	-	3.2	$Z' \text{ mass}$ 1.5 TeV	1603.08791
	SSM $W' \rightarrow \ell\nu$	$1 e, \mu$	-	Yes	13.3	$W' \text{ mass}$ 4.74 TeV	ATLAS-CONF-2016-061
	HVT $W' \rightarrow WZ \rightarrow qq\nu\nu$ model A	$0 e, \mu$	$1 J$	Yes	13.2	$W' \text{ mass}$ 2.4 TeV	$g_V = 1$ ATLAS-CONF-2016-082
	HVT $W' \rightarrow WZ \rightarrow qqqq$ model B	-	$2 J$	-	15.5	$W' \text{ mass}$ 3.0 TeV	ATLAS-CONF-2016-055
	HVT $V' \rightarrow WH/ZH$ model B	multi-channel	-	-	3.2	$V' \text{ mass}$ 2.31 TeV	$g_V = 3$ 1607.05621
	LRSM $W'_R \rightarrow tb$	$1 e, \mu$	$2 b, 0-1 j$	Yes	20.3	$W'_R \text{ mass}$ 1.92 TeV	1410.4103
LRSM $W'_R \rightarrow tb$	$0 e, \mu$	$\geq 1 b, 1 J$	-	20.3	$W'_R \text{ mass}$ 1.76 TeV	1408.0886	
CI	CI $qqqq$	-	$2 j$	-	15.7	Λ 19.9 TeV $\eta_{LL} = -1$	ATLAS-CONF-2016-069
	CI $\ell\ell qq$	$2 e, \mu$	-	-	3.2	Λ 25.2 TeV $\eta_{LL} = -1$	1607.03669
	CI $uutt$	$2(SS) \geq 3 e, \mu \geq 1 b, \geq 1 j$	Yes	20.3	Λ 4.9 TeV	$ C_{RR} = 1$ 1504.04605	
DM	Axial-vector mediator (Dirac DM)	$0 e, \mu$	$\geq 1 j$	Yes	3.2	m_A 1.0 TeV	$g_0=0.25, g_1=1.0, m(\chi) < 250 \text{ GeV}$ 1604.07773
	Axial-vector mediator (Dirac DM)	$0 e, \mu, 1 \gamma$	$1 j$	Yes	3.2	m_A 710 GeV	$g_0=0.25, g_1=1.0, m(\chi) < 150 \text{ GeV}$ 1604.01306
	$ZZ\chi\chi$ EFT (Dirac DM)	$0 e, \mu$	$1 J, \leq 1 j$	Yes	3.2	M_χ 550 GeV	$m(\chi) < 150 \text{ GeV}$ ATLAS-CONF-2015-080
LQ	Scalar LQ 1 st gen	$2 e$	$\geq 2 j$	-	3.2	$LQ \text{ mass}$ 1.1 TeV	$\beta = 1$ 1605.06035
	Scalar LQ 2 nd gen	2μ	$\geq 2 j$	-	3.2	$LQ \text{ mass}$ 1.05 TeV	$\beta = 1$ 1605.06035
	Scalar LQ 3 rd gen	$1 e, \mu$	$\geq 1 b, \geq 3 j$	Yes	20.3	$LQ \text{ mass}$ 640 GeV	$\beta = 0$ 1508.04735
Heavy quarks	VLQ $TT \rightarrow Ht + X$	$1 e, \mu$	$\geq 2 b, \geq 3 j$	Yes	20.3	$T \text{ mass}$ 855 GeV	T in (T,B) doublet 1505.04306
	VLQ $YY \rightarrow Wb + X$	$1 e, \mu$	$\geq 1 b, \geq 3 j$	Yes	20.3	$Y \text{ mass}$ 770 GeV	Y in (B,Y) doublet 1505.04306
	VLQ $BB \rightarrow Hb + X$	$1 e, \mu$	$\geq 2 b, \geq 3 j$	Yes	20.3	$B \text{ mass}$ 735 GeV	isospin singlet 1505.04306
	VLQ $BB \rightarrow Zb + X$	$2/\geq 3 e, \mu$	$\geq 2/\geq 1 b$	-	20.3	$B \text{ mass}$ 755 GeV	B in (B,Y) doublet 1409.5500
	VLQ $QQ \rightarrow WqWq$	$1 e, \mu$	$\geq 4 j$	Yes	20.3	$Q \text{ mass}$ 690 GeV	1509.04261
	VLQ $T_{5/3} T_{5/3} \rightarrow WtWt$	$2(SS) \geq 3 e, \mu \geq 1 b, \geq 1 j$	Yes	3.2	$T_{5/3} \text{ mass}$ 990 GeV	ATLAS-CONF-2016-032	
Excited fermions	Excited quark $q^* \rightarrow q\gamma$	1γ	$1 j$	-	3.2	$q^* \text{ mass}$ 4.4 TeV	only u^* and d^* , $\Lambda = m(q^*)$ 1512.05910
	Excited quark $q^* \rightarrow qg$	-	$2 j$	-	15.7	$q^* \text{ mass}$ 5.6 TeV	only u^* and d^* , $\Lambda = m(q^*)$ ATLAS-CONF-2016-069
	Excited quark $b^* \rightarrow bg$	-	$1 b, 1 j$	-	8.8	$b^* \text{ mass}$ 2.3 TeV	ATLAS-CONF-2016-060
	Excited quark $b^* \rightarrow Wt$	$1 \text{ or } 2 e, \mu$	$1 b, 2-0 j$	Yes	20.3	$b^* \text{ mass}$ 1.5 TeV	$f_g = f_L = f_R = 1$ 1510.02664
	Excited lepton ℓ^*	$3 e, \mu$	-	-	20.3	$\ell^* \text{ mass}$ 3.0 TeV	$\Lambda = 3.0 \text{ TeV}$ 1411.2921
	Excited lepton ν^*	$3 e, \mu, \tau$	-	-	20.3	$\nu^* \text{ mass}$ 1.6 TeV	$\Lambda = 1.6 \text{ TeV}$ 1411.2921
Other	LSTC $a_T \rightarrow W\gamma$	$1 e, \mu, 1 \gamma$	-	Yes	20.3	$a_T \text{ mass}$ 960 GeV	1407.8150
	LRSM Majorana ν	$2 e, \mu$	$2 j$	-	20.3	$N^0 \text{ mass}$ 2.0 TeV	1506.06020
	Higgs triplet $H^{\pm\pm} \rightarrow ee$	$2 e (SS)$	-	-	13.9	$H^{\pm\pm} \text{ mass}$ 570 GeV	$m(W_R) = 2.4 \text{ TeV, no mixing}$ DY production, BR($H^{\pm\pm} \rightarrow ee$)=1 ATLAS-CONF-2016-051
	Higgs triplet $H^{\pm\pm} \rightarrow \ell\tau$	$3 e, \mu, \tau$	-	-	20.3	$H^{\pm\pm} \text{ mass}$ 400 GeV	DY production, BR($H^{\pm\pm} \rightarrow \ell\tau$)=1 1411.2921
	Monotop (non-res prod)	$1 e, \mu$	$1 b$	Yes	20.3	$\text{spin-1 invisible particle mass}$ 657 GeV	$a_{\text{non-res}} = 0.2$ 1410.5404
	Multi-charged particles	-	-	-	20.3	$\text{multi-charged particle mass}$ 785 GeV	DY production, $ q = 5e$ 1504.04188
	Magnetic monopoles	-	-	-	7.0	monopole mass 1.34 TeV	DY production, $ g = 1g_D, \text{spin } 1/2$ 1509.08059

$\sqrt{s} = 8 \text{ TeV}$

$\sqrt{s} = 13 \text{ TeV}$

10^{-1}

1

10

Mass scale [TeV]

*Only a selection of the available mass limits on new states or phenomena is shown. Lower bounds are specified only when explicitly not excluded.

†Small-radius (large-radius) jets are denoted by the letter j (J).

incorporating gravity into the SM

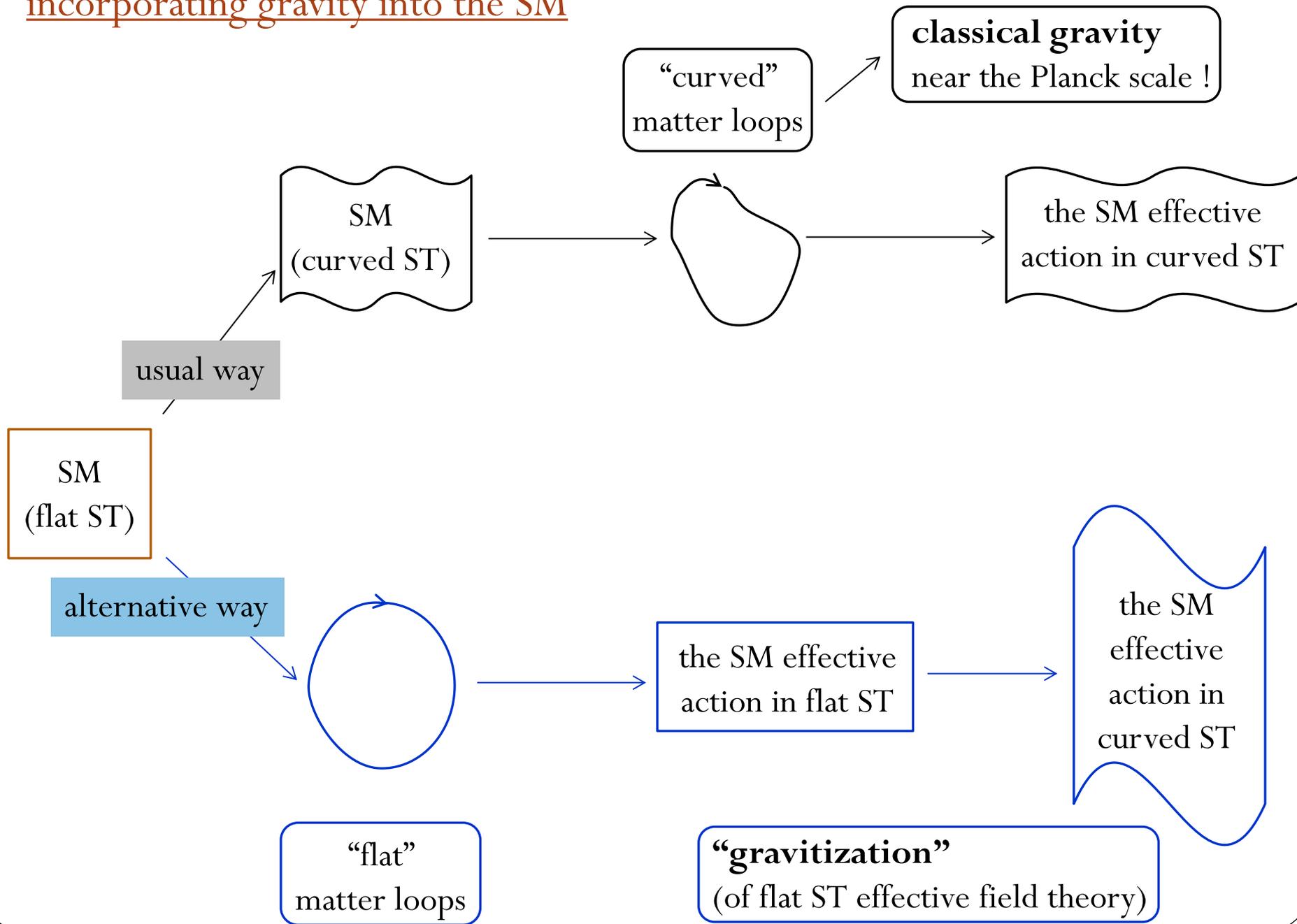
carry the SM into **classical**
curved spacetime

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graph TD; A[carry the SM into classical curved spacetime] --> B[inconsistent due to failure of the wave-particle duality]; B --> C[makes sense only as effective theory];
```

inconsistent due to failure of
the **wave-particle duality**

makes sense only as
effective theory

incorporating gravity into the SM

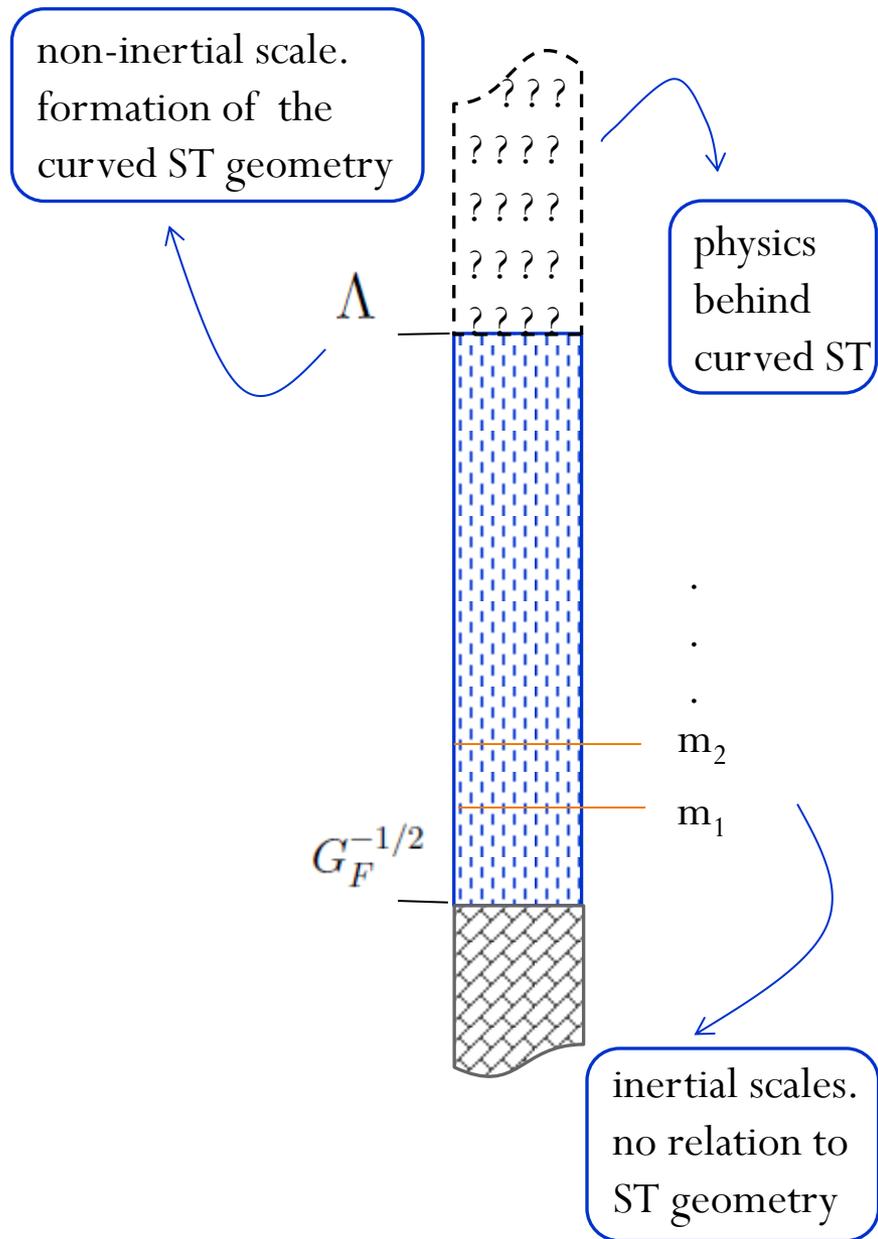


the UV scale of the SM

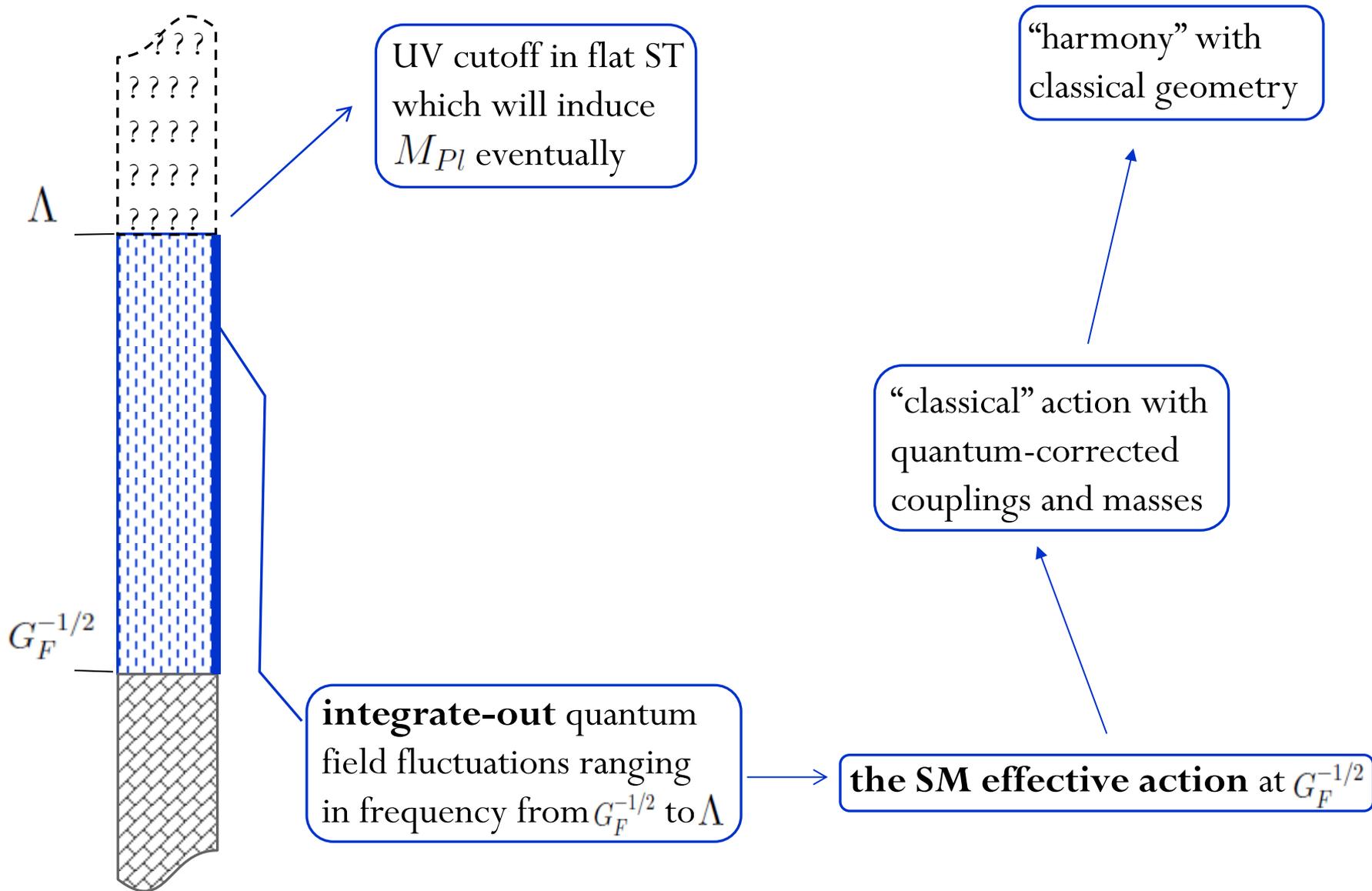
there are two distinct scales in Nature:

“**inertial scales**” pertaining to inertia of particles. **the Fermi scale** is an inertial scale deriving from the W boson mass.

“**non-inertial scales**” pertaining to gravity. the Planck scale is a non-inertial scale relating stress-energy to curvature.

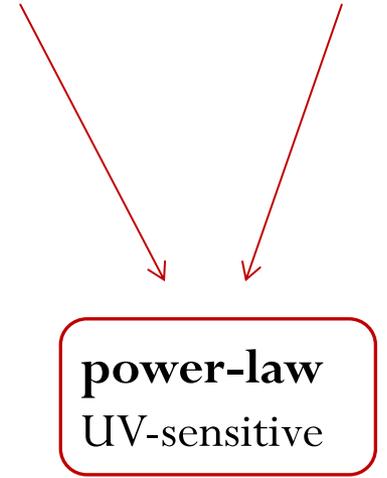
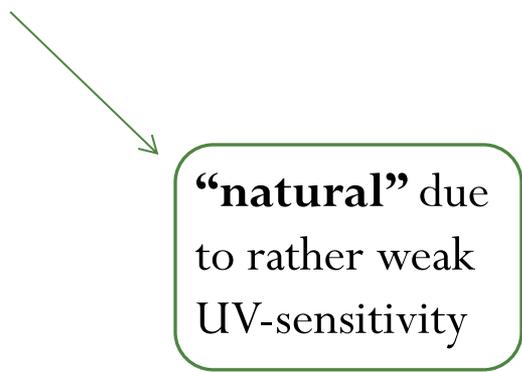
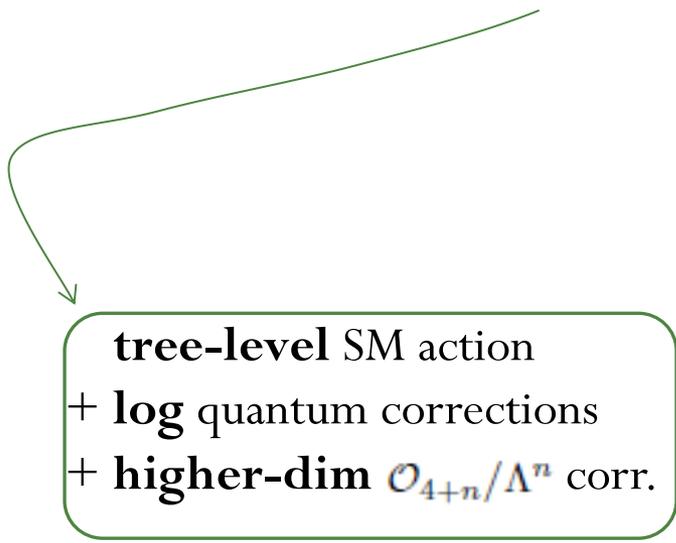


the SM effective action in flat ST



the SM effective action in flat ST

$$S_{\Lambda}(\eta) = S(\eta, \psi_{SM}, G_F^{-1} \log(G_F \Lambda^2)) + S_{\Lambda}^0(\eta) + S_{\Lambda}^1(\eta)$$



the SM effective action in flat ST

$$S_{\Lambda}^0(\eta) = \int d^4x \sqrt{\|\eta\|} \{ a\Lambda^4 + a_m \Lambda^2 m_H^2 + b\Lambda^2 H^\dagger H \}$$

quartically
UV-sensitive
vacuum energy

“unnatural”

quadratically
UV-sensitive Higgs
mass-squared

“unnatural”

the SM effective action in flat ST

$$S_{\Lambda}^1(\eta) = \int d^4x \sqrt{\|\eta\|} c_V \Lambda^2 \eta_{\mu\nu} \text{Tr}\{V^{\mu}V^{\nu}\}$$

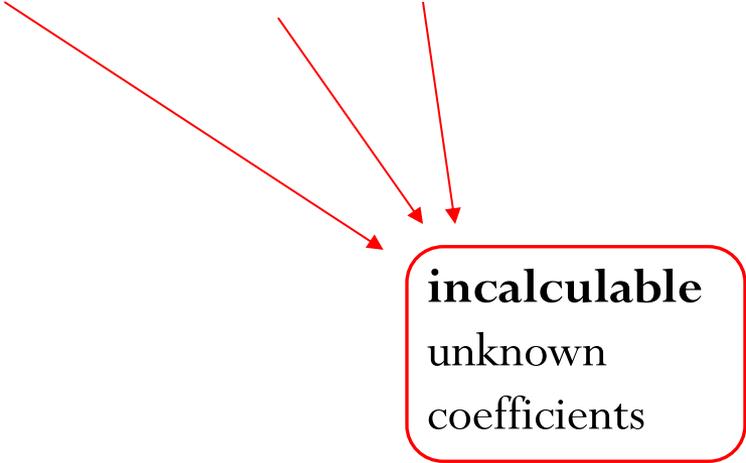
quadratically
UV-sensitive
gauge boson
mass-squareds:
“unnatural”

all gauge symmetries
are **explicitly** broken

adding curvature as usual

$$S_{\Lambda}^1(\eta) \xrightarrow[\text{comma} \rightarrow \text{semicolon}]{\eta_{\mu\nu} \prec g_{\mu\nu}} \int d^4x \sqrt{\|g\|} c_V \Lambda^2 g_{\mu\nu} \text{Tr}\{V^\mu V^\nu\}$$

$$\xrightarrow{\text{add curvature}} \int d^4x \sqrt{\|g\|} \left[c_V \Lambda^2 g_{\mu\nu} \text{Tr}\{V^\mu V^\nu\} \right. \\ \left. + M^2 R(g) + V + c_R R(g)^2 + \dots \right]$$



incalculable
unknown
coefficients

adding curvature by gauge invariance

$$S_{\Lambda}^1(\eta) = S_{\Lambda}^1(\eta) - \int d^4x \sqrt{\|\eta\|} \frac{c_V}{2} \text{Tr} \{ \eta_{\mu\alpha} \eta_{\nu\beta} V^{\mu\nu} V^{\alpha\beta} \} + \int d^4x \sqrt{\|\eta\|} \frac{c_V}{2} \text{Tr} \{ \eta_{\mu\alpha} \eta_{\nu\beta} V^{\mu\nu} V^{\alpha\beta} \}$$

$$\begin{aligned} & \underline{\text{by-parts}} \quad - \int d^4x \sqrt{\|\eta\|} \frac{c_V}{2} \text{Tr} \{ \eta_{\mu\alpha} \eta_{\nu\beta} V^{\mu\nu} V^{\alpha\beta} \} \\ & + \int d^4x \sqrt{\|\eta\|} c_V \text{Tr} \{ V^{\mu} (-D^2 \eta_{\mu\nu} + D_{\mu} D_{\nu} + V_{\mu\nu} + \Lambda^2 \eta_{\mu\nu}) V^{\nu} \} \\ & + \int d^4x \sqrt{\|\eta\|} c_V \text{Tr} \{ D_{\mu} (\eta_{\alpha\beta} V^{\alpha} V^{\beta\mu}) \} \end{aligned}$$

$$\begin{aligned} & \underline{\underline{\eta_{\mu\nu} \prec g_{\mu\nu}}} \quad - \int d^4x \sqrt{\|g\|} \frac{c_V}{2} \text{Tr} \{ g_{\mu\alpha} g_{\nu\beta} V^{\mu\nu} V^{\alpha\beta} \} \\ & \text{comma} \rightarrow \text{semicolon} \\ & + \int d^4x \sqrt{\|g\|} c_V \text{Tr} \{ V^{\mu} (-\mathcal{D}^2 g_{\mu\nu} + \mathcal{D}_{\mu} \mathcal{D}_{\nu} + V_{\mu\nu} + \Lambda^2 g_{\mu\nu}) V^{\nu} \} \\ & + \int d^4x \sqrt{\|g\|} c_V \text{Tr} \{ \mathcal{D}_{\mu} (g_{\alpha\beta} V^{\alpha} V^{\beta\mu}) \} \end{aligned}$$

$$\begin{aligned} & \underline{\underline{\Lambda^2 g_{\mu\nu} \prec R_{\mu\nu}({}^g\Gamma)}} \quad - \int d^4x \sqrt{\|g\|} \frac{c_V}{2} \text{Tr} \{ g_{\mu\alpha} g_{\nu\beta} V^{\mu\nu} V^{\alpha\beta} \} \\ & \text{gauge invariance} \\ & + \int d^4x \sqrt{\|g\|} c_V \text{Tr} \{ V^{\mu} (-\mathcal{D}^2 g_{\mu\nu} + \mathcal{D}_{\mu} \mathcal{D}_{\nu} + V_{\mu\nu} + R_{\mu\nu}({}^g\Gamma)) V^{\nu} \} \\ & + \int d^4x \sqrt{\|g\|} c_V \text{Tr} \{ \mathcal{D}_{\mu} (g_{\alpha\beta} V^{\alpha} V^{\beta\mu}) \} \end{aligned}$$

$$\underline{\underline{\text{by-parts back}}} \quad - \int d^4x \sqrt{\|g\|} \frac{c_V}{2} \text{Tr} \{ g_{\mu\alpha} g_{\nu\beta} V^{\mu\nu} V^{\alpha\beta} \} + \int d^4x \sqrt{\|g\|} \frac{c_V}{2} \text{Tr} \{ g_{\mu\alpha} g_{\nu\beta} V^{\mu\nu} V^{\alpha\beta} \}$$

$$= 0$$

adding curvature by gauge invariance

$$\underbrace{S_{\Lambda}^1(\eta)}_{\text{flat ST}} \xrightarrow{(\eta_{\mu\nu} \rightarrow g_{\mu\nu}) \text{ and } (\Lambda^2 g_{\mu\nu} \rightarrow R_{\mu\nu})} \underbrace{0}_{\text{curved ST}}$$

$S_{\Lambda}^1(\eta)$ is **eradicated** !

gauge symmetries are
restored at the UV!

a way is revealed for
incorporating
gravity into the SM

the SM effective action in curved ST

the SM in curved spacetime must involve:

no extra couplings not found in $S_\Lambda(\eta)$ as no quantum loops are left to induce any new coupling

no curvature-free term as curved geometry must disappear as soon as quantum corrections are removed:

$$\tilde{S}_\Lambda^0(g, R) \Big|_{R=0} = S_\Lambda^0(\eta) \Big|_{\Lambda=0}$$

no new forces other than gravity as spacetime can attain required elasticity if Λ nears M_{Pl}

the SM effective action in curved ST

$$S_{\Lambda}^0(\eta) + S_{\Lambda}^1(\eta) \rightarrow \tilde{S}_{\Lambda}^0(g, R) = \int d^4x \sqrt{\|g\|} (a\Lambda^2 + a_m m_H^2 + bH^\dagger H) \frac{R(g)}{4}$$

the Einstein-Hilbert term
**(no power-law UV
contributions to the
cosmological constant !)**

CC is reduced to the
neutrino mass scale !

Higgs-curvature coupling
**(no quadratic UV
contributions to the
Higgs boson mass !)**

the SM Higgs sector is naturalized
(gauge hierarchy problem disappears!)

need to New Physics

There is a crucial problem:

$$a = \frac{1}{64\pi^2} (n_b - n_f) = \frac{1}{64\pi^2} (28 - 90) = -\frac{62}{64\pi^2} < 0$$

the SM spectrum alone leads to
“repulsive” gravity!

an **NP** is needed to make
gravity **“attractive”**

the NP **does not have to**
interact with the SM !

the NP particle spectrum

$$\tilde{S}_\Lambda^{SM+NP}(g, R) = \int d^4x \sqrt{||g||} \left(\frac{1}{2} M_{Pl}^2 R(g) + \dots \right)$$

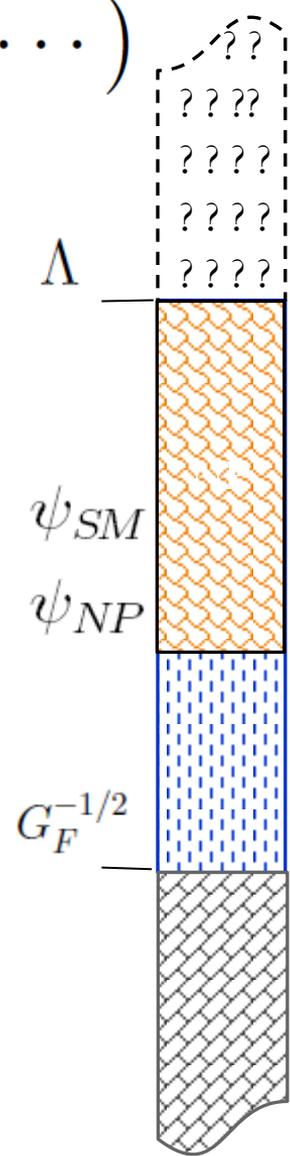
$$M_{Pl}^2 \cong \frac{1}{2} (a + a^{NP}) \Lambda^2$$

gravity attracts if:

$$n_b^{NP} - n_f^{NP} \geq 63$$

$\Lambda < M_{Pl}$ provided that

$$n_b^{NP} - n_f^{NP} > 128\pi^2 + 62 \approx 1325$$



coupling between the NP and the SM

in gravitization, the NP and the SM
do not have to interact

non-interacting

the NP can have only
gravitational effects

the **Dark Matter**
and **Dark Energy**

interacting

the NP can be **SM-charged** to
cause **strong** and **electroweak**
effects (*e.g.* 2HDM, GUTs, LR)

the NP can be **SM-singlet** to
couple through the **Higgs**,
hypercharge and **lepton** portals

various **collider** (new particles
at the LHC) and **astrophysical**
(dark matter) signatures

impact of interacting NP: the log-naturalness problem

Scalars S in NP, with coupling $\lambda_{HS}H^\dagger HS^\dagger S$ to Higgs, give rise to

$$\delta m_h^2 \propto \lambda_{HS} m_S^2 \log G_F m_S^2$$

that **destabilizes** the SM Higgs sector unless $m_S \sim G_F^{-1/2}$!

The NP fields that can cause the log-naturalness problem must be either **Fermi-weight** or just **absent** ! They do not have to exist for gravitization to work but if they exist they must weigh at the Fermi scale.

The LHC, with sufficient statistics, can discover

- New scalars
- New vector-like fermions
- New non-gauge vectors

if they exist.

natural setup

The UV-natural setup is:

$$\begin{aligned}\tilde{S}_\Lambda^{SM+NP}(g) &= S(g, \psi_{SM}, \psi_{NP}, G_F^{-1} \log(G_F \Lambda^2)) \\ &+ \int d^4x \sqrt{\|g\|} \left(\frac{1}{2} M_{Pl}^2 R(g) + \zeta_H R(g) H^\dagger H + \zeta_S R(g) S^\dagger S \right) \\ &+ \delta S(g, \psi_{SM}, \psi_{NP}, \Lambda_{NP}^2 \log(G_F \Lambda_{NP}^2))\end{aligned}$$

possible to reinterpret in **Dimensional Regularization** after the identification

$$\log(G_F \Lambda^2) \equiv 2/\epsilon + \log G_F \mu^2$$

in a momentum space of dimension

$$D = 4 - \epsilon \text{ and volume } \mu^{2\epsilon} \infty^{4-2\epsilon}$$

can cause the **log-naturalness problem** unless $\Lambda_{NP} \sim G_F^{-1/2}$

a rough model of the NP

- $E(8) \otimes E(8) \otimes E(8)$ gauge theory
- Possible $SU(N)$ factors
- Possible singlet fermions
- Possible $U(1)$ factors
- Scalars, vector-like fermions, non-gauge vectors (weighing at the Fermi scale).

inflation

An SU(2) gauge field in the NP leads to successful inflation:

$$\int d^4x \sqrt{\|g\|} \left(-\frac{1}{2} \text{Tr} \{ F_{\mu\nu} F^{\mu\nu} \} + \frac{1}{\Lambda^4} \left(\text{Tr} \{ F_{\mu\nu} \tilde{F}^{\mu\nu} \} \right)^2 \right)$$

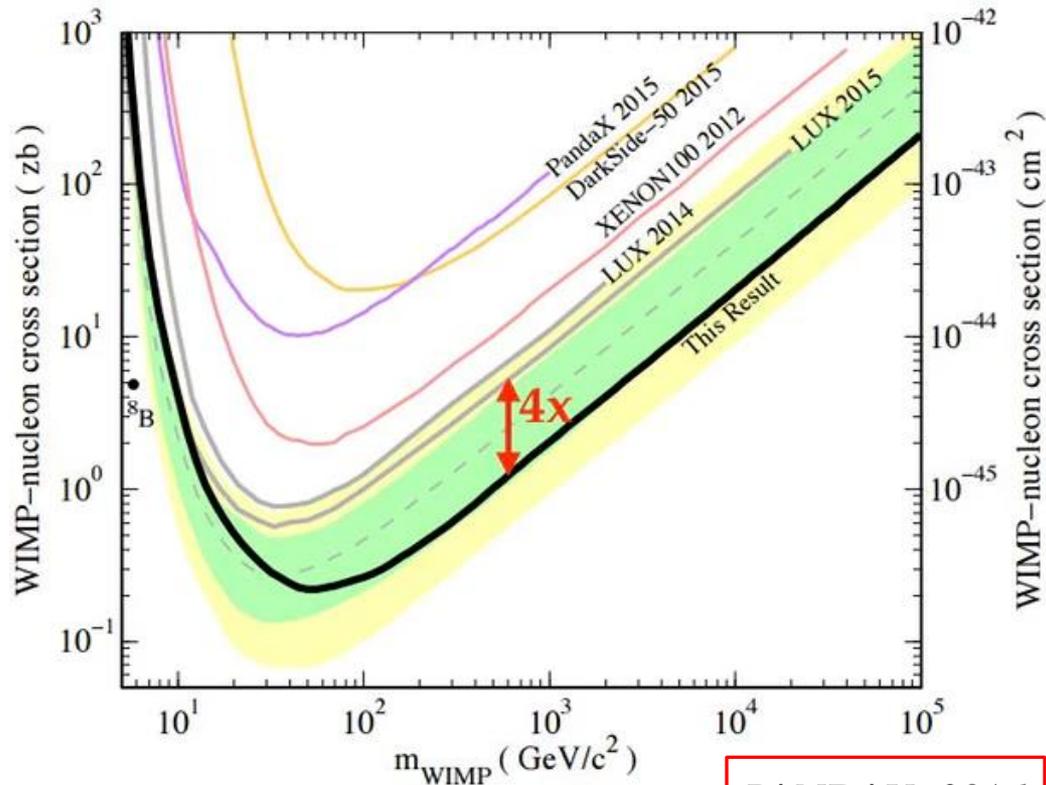
$$\Lambda \approx 1.7 \times 10^{-3} M_{Pl}$$

a matter of
 $n_b^{NP} - n_f^{NP}$

Sheikh-Jabbari & Maleknejad, 2011

the Dark Matter

the SM and the NP do not have to interact for gravitization to work.
non-interacting DM (**ebony matter**) respects UV-naturalness, agrees with null WIMP searches, and stands therefore as **nominal** prediction of gravitization. This setup can vary according interacting DM schemes.



Peebles & Vilenkin, 1999

PANDAX, 2016

contrasting with extra dimensions and supersymmetry

	Extra Dimensions ($\Lambda \simeq \text{TeV}$)	Supersymmetry (Λ : Not Fixed)	Gravitization ($\Lambda \simeq M_{Pl}$)
NP	Necessary	Necessary	Necessary
Bosons-Fermions	Not Fixed	0	$\gtrsim 128\pi^2$
NP-SM Interaction	Necessary	Necessary	Not Necessary
Scale of NP	TeV	TeV	Not Fixed
Nature of Λ	Non-Inertial	Inertial	Non-Inertial
Gravity	Included	Not Included	Included
Spacetime Dimensions	> 4	4	4
Natural DM Candidate	None	Lightest Sparticle	Ebony Matter
UV-Naturalness Problem	Solved	Solved	Solved
Log-Naturalness Problem	Solved	Not Solved	Not Necessarily Exist
Tension with LHC Results	Yes	Yes	No
Tension with WIMP Searches	Yes	Yes	No

summary/conclusion

SM

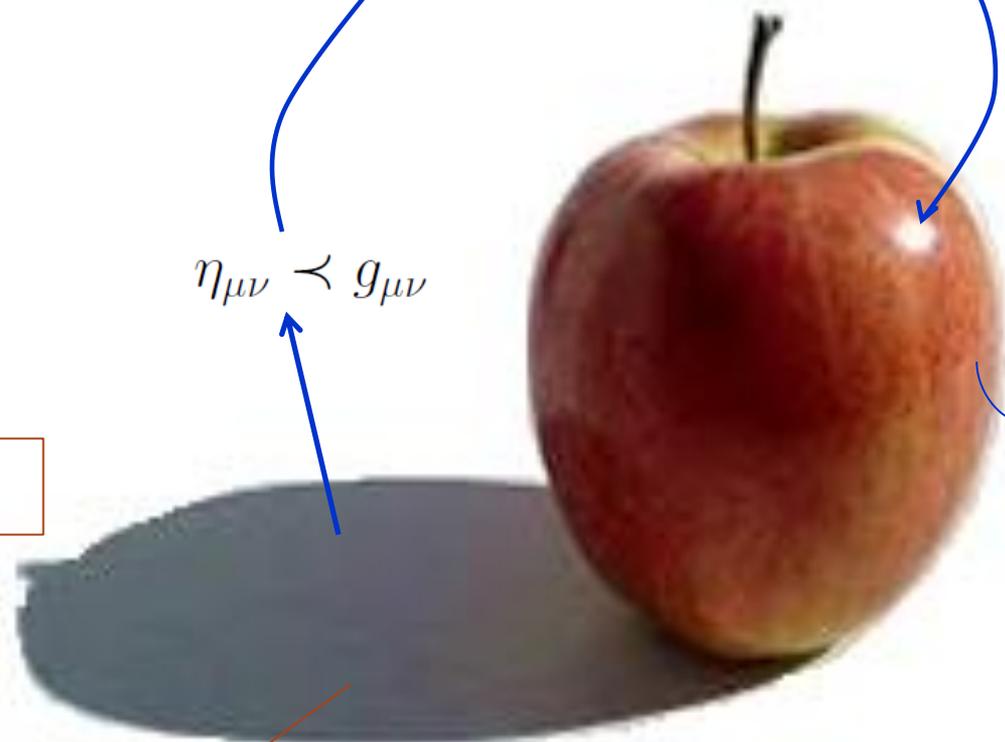
$$\eta_{\mu\nu} \prec g_{\mu\nu}$$

$$\Lambda^2 g_{\mu\nu} \prec R_{\mu\nu}(g)$$

SM + NP

- unnatural
- broken gauge symmetry
- no gravity
- no dark matter

- ✓ natural
- ✓ exact gauge symmetry
- ✓ gravity
- ✓ dark matter
- ✓ inflaton
- ✓ v-size CC
- ✓ TeV New Phys.



[see also:](#)

A Mechanism of Ultraviolet Naturalness

Durmus Ali Demir

(Submitted on 19 Oct 2015 (v1), last revised 3 May 2016 (this version, v2))

A naturalization mechanism is revealed by integrating-in spacetime curvature upon flat spacetime effective field theories with Planckian ultraviolet scales such that, quartic ultraviolet contributions to vacuum energy transmute into Einstein-Hilbert gravity and quadratic ultraviolet contributions to scalar masses turn into scalar curvature-scalar field nonminimal couplings. Extensions of the Standard Model (SM) having at least 63 more bosons than fermions enjoy this mechanism. They do not have to interact with the SM for the mechanism to work. They can form a secluded sector to source noninteracting dark matter observable via only its weight, or a weakly-coupled sector to source dark matter and various collider signals.

Comments: Improved discussions, clarified subtle points, added references; 3 pages

Subjects: **High Energy Physics - Phenomenology (hep-ph)**; General Relativity and Quantum Cosmology (gr-qc); High Energy Physics - Theory (hep-th)

Report number: IZTECH-HEP-04/2015

Cite as: [arXiv:1510.05570](https://arxiv.org/abs/1510.05570) [hep-ph]

the talk is based on:

Curvature-Restored Gauge Invariance and Ultraviolet Naturalness

[Durmus Ali Demir](#)

(Submitted on 2 May 2016)

It is shown that, $(a\Lambda^2 + b|H|^2)R$ in a spacetime of curvature R is a natural ultraviolet (UV) completion of $(a\Lambda^4 + b\Lambda^2|H|^2)$ in the flat-spacetime Standard Model (SM) with Higgs field H , UV scale Λ and loop factors a, b . This curvature completion rests on the fact that a Λ -mass gauge theory in flat spacetime turns, on the cut-view $R=4\Lambda^2$, into a massless gauge theory in curved spacetime. It provides a symmetry reason for curved spacetime, wherein gravity and matter are both low-energy effective phenomena. Gravity arises correctly if new physics exists with at least 63 more bosons than fermions, with no need to interact with the SM and with dark matter as a natural harbinger. It can source various cosmological, astrophysical and collider phenomena depending on its spectrum and couplings to the SM.

Comments: 3 pp

Subjects: **High Energy Physics - Phenomenology (hep-ph)**; Cosmology and Nongalactic Astrophysics (astro-ph.CO); General Relativity and Quantum Cosmology (gr-qc); High Energy Physics - Theory (hep-th)

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