GRAVITIZATION

OF EFFECTIVE FIELD THEORY AND ULTRAVIOLET STABILITY

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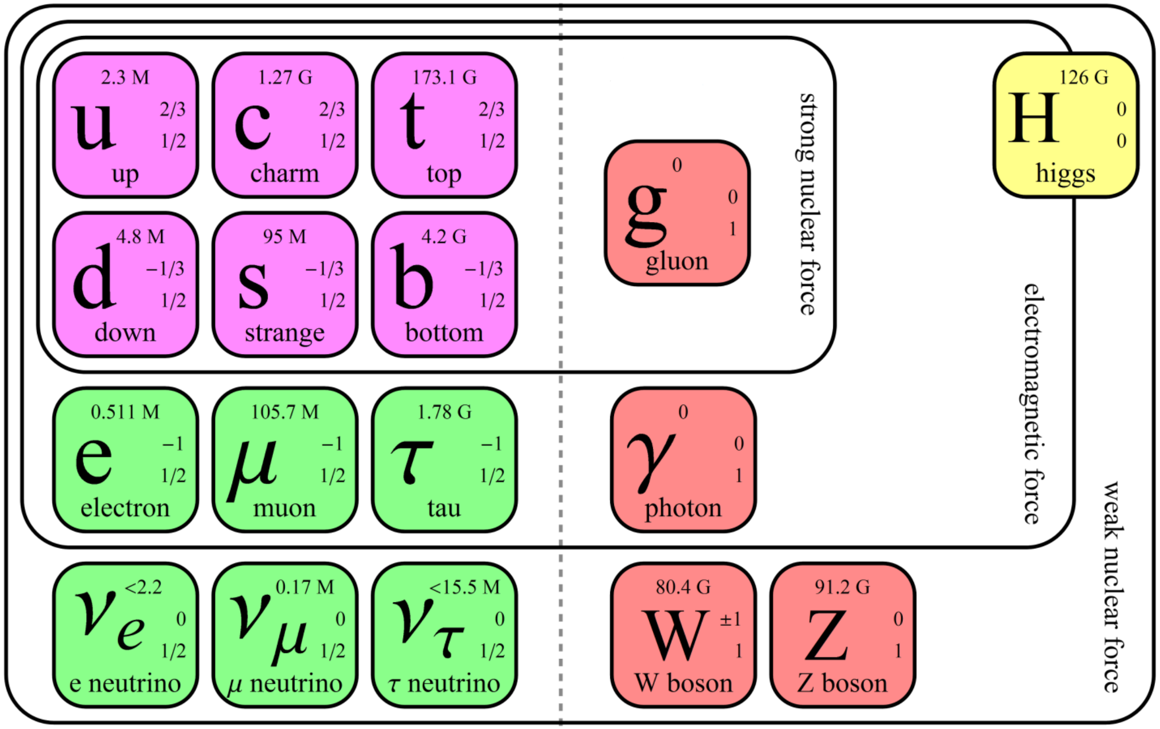
the Standard Model

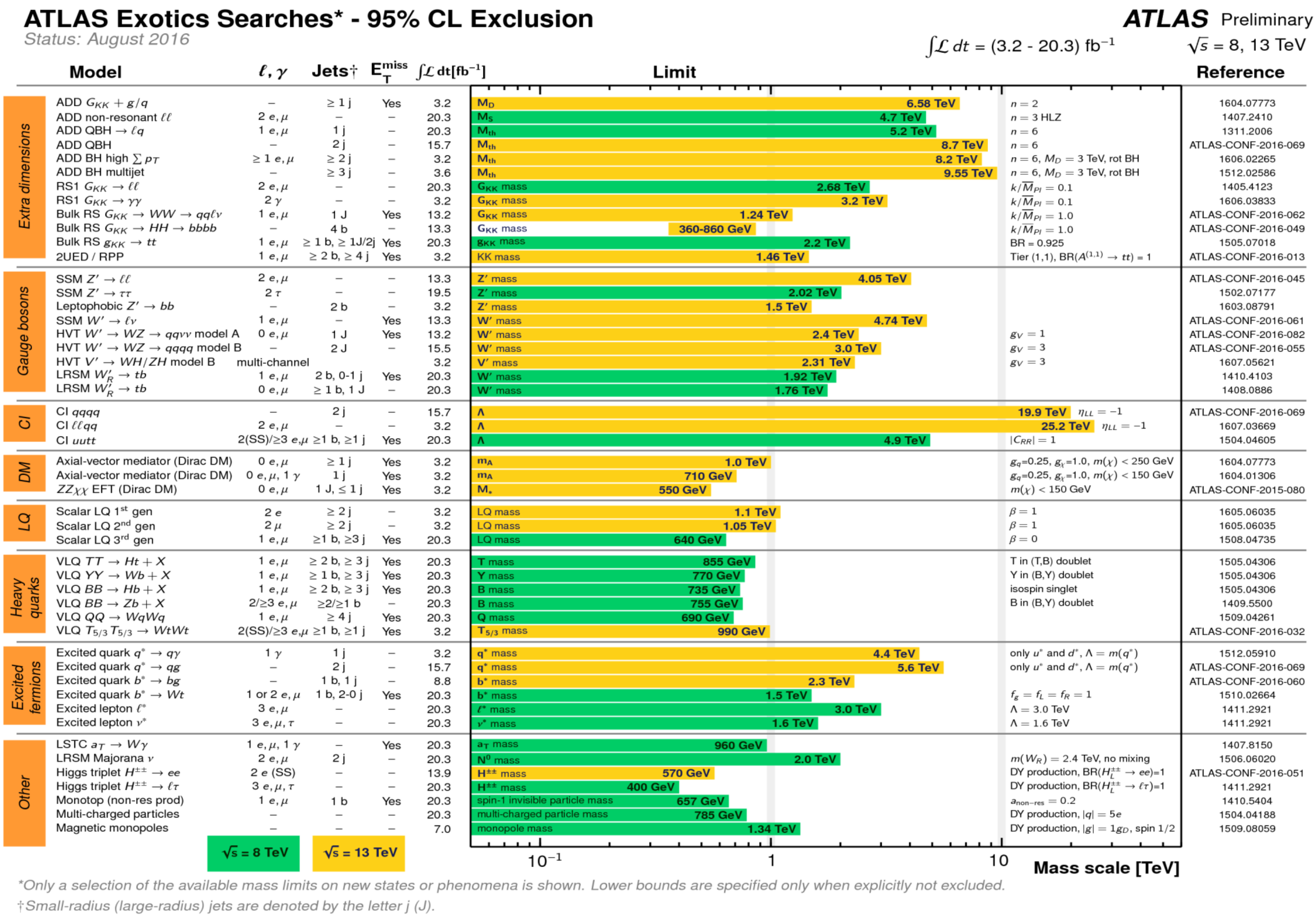


fully confirmed by **experiments**

does not include **gravity**

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

the SM continues to hold at high energies

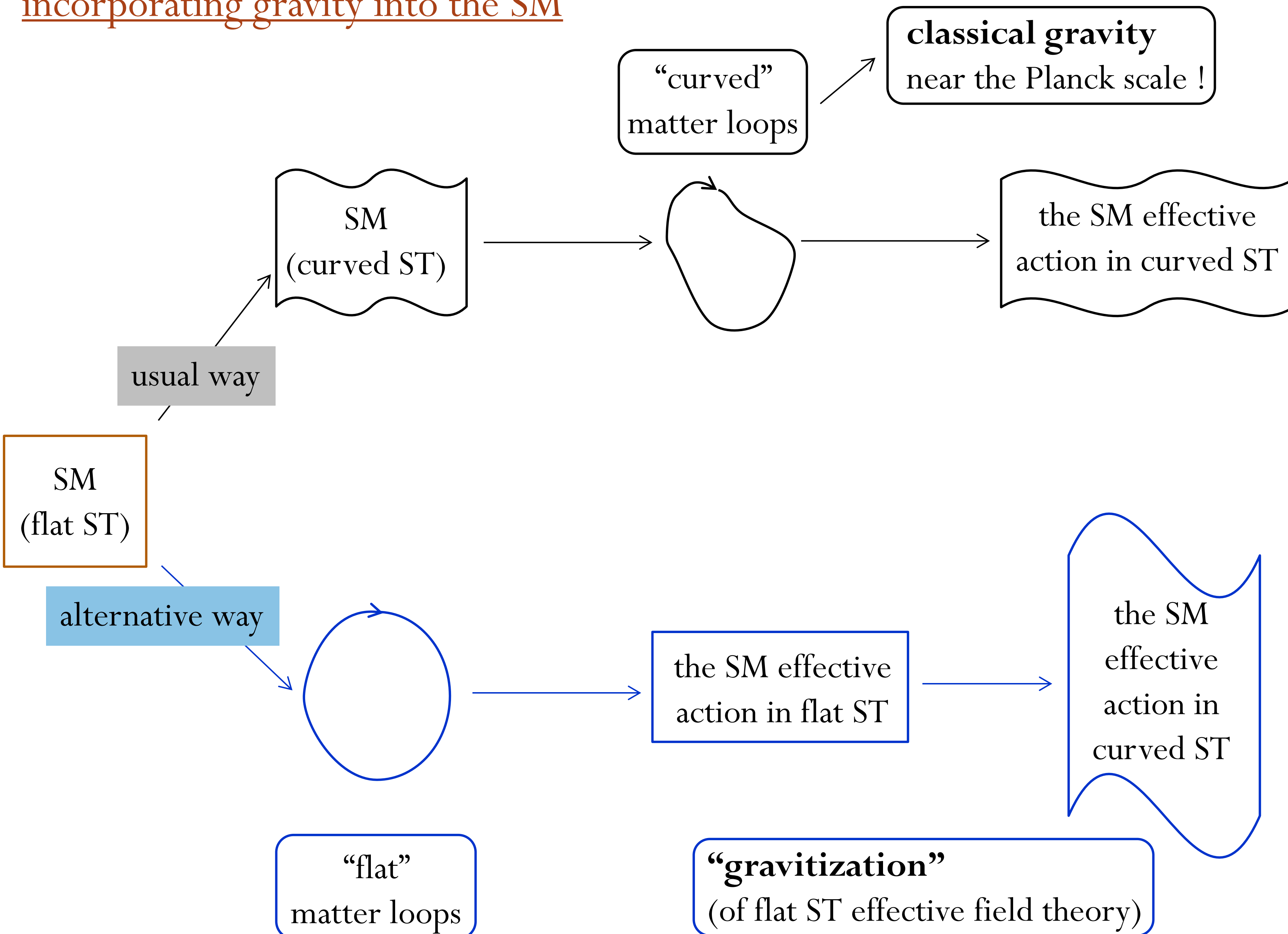


incorporating gravity into the SM

carry the SM into **classical** curved spacetime

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

makes sense only as **effective theory** incorporating gravity into the SM

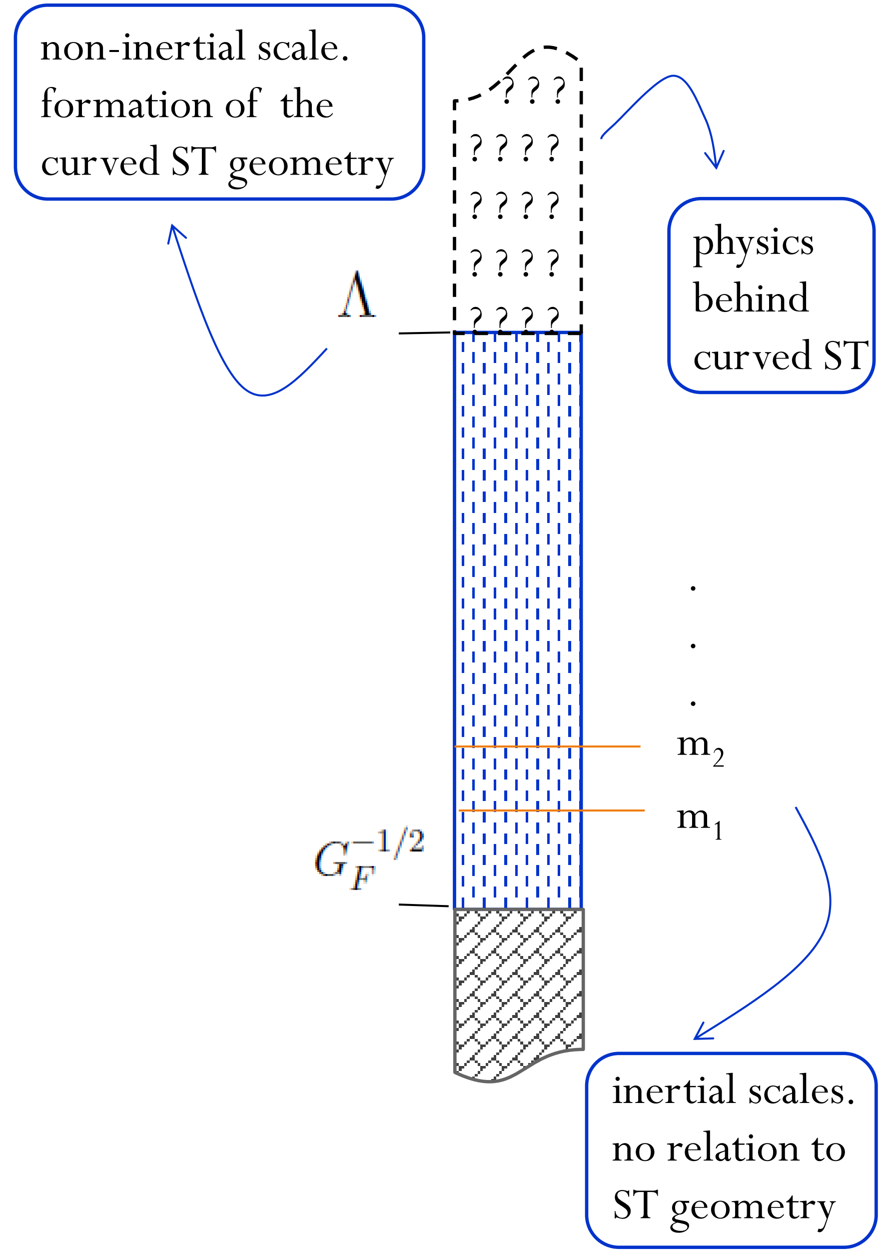


the UV scale of the SM

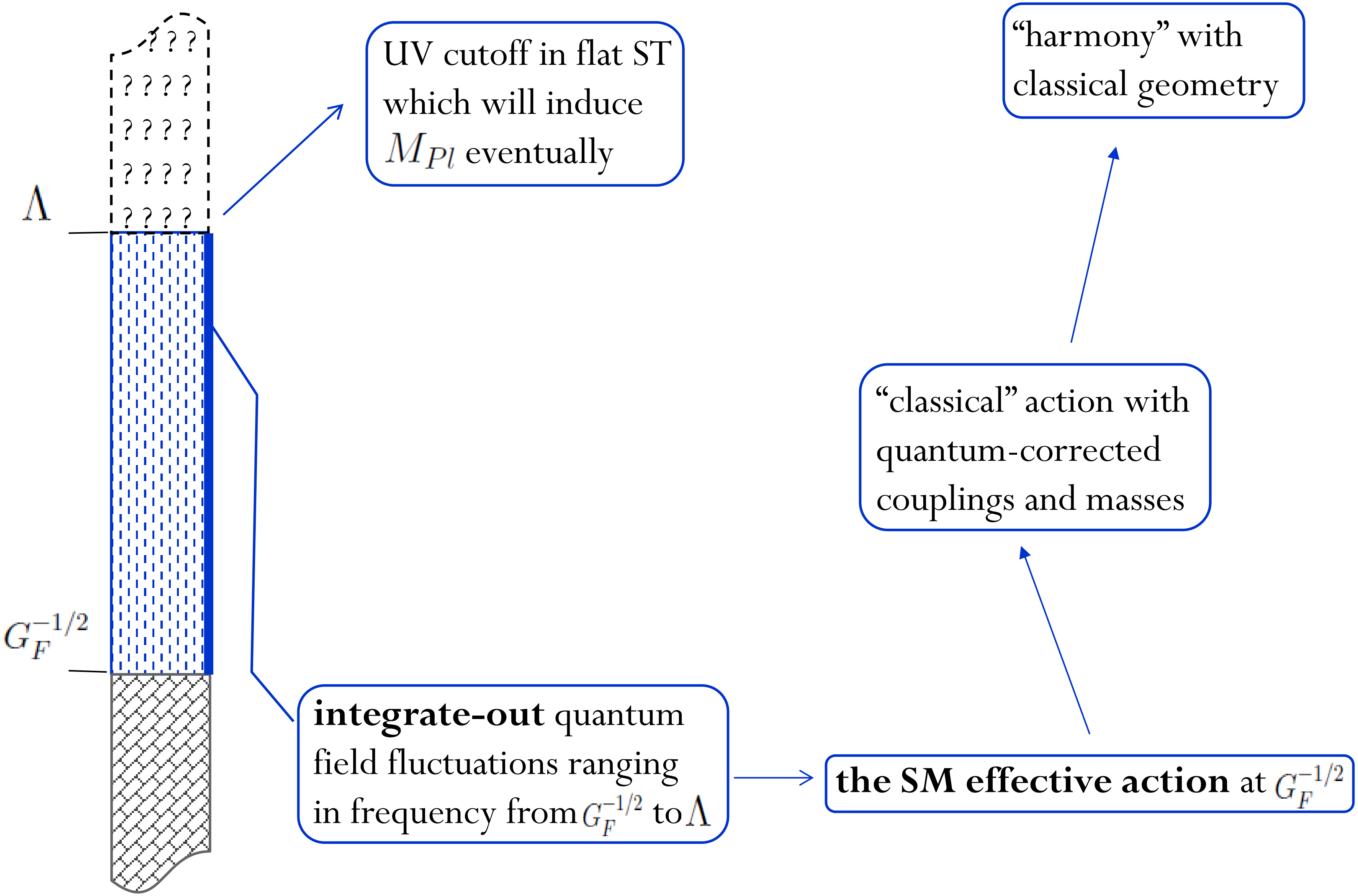
there are two distinct scales in Nature:

“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

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

tree-level SM action
\+ **log** quantum corrections
\+ **higher-dim** $\mathcal{O}_{4+n}/\Lambda^n$ corr.

power-law
UV-sensitive

"natural" due to rather weak UV-sensitivity

the SM effective action in flat ST

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

quartically UV-sensitive vacuum energy

"unnatural"

quadratically UV-sensitive Higgs mass-squared

"unnatural"

the SM effective action in flat ST

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

quadratically UV-sensitive gauge boson mass-squareds: **"unnatural"**

all gauge symmetries are **explicitly** broken

adding curvature as usual

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

$$\xrightarrow{\text{add curvature}} \int d^4x\sqrt{\|g\|}\Big[c_V\Lambda^2 g_{\mu\nu}\mathrm{Tr}\{V^\mu V^\nu\}$$

$$+ \quad M^2R(g) + V + c_R R(g)^2 + \dots\Big]$$

incalculable
unknown
coefficients

adding curvature by gauge invariance

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

$$\stackrel{\text{by-parts}}{=\!=} \; -\int d^4x\sqrt{\|\eta\|}\frac{c_V}{2}\mathrm{Tr}\{\eta_{\mu\alpha}\eta_{\nu\beta}V^{\mu\nu}V^{\alpha\beta}\}$$

$$+ \int d^4x\sqrt{\|\eta\|}c_V\mathrm{Tr}\{V^\mu\left(-D^2\eta_{\mu\nu} + D_\mu D_\nu + V_{\mu\nu} + \Lambda^2\eta_{\mu\nu}\right)V^\nu\}$$

$$+ \int d^4x\sqrt{\|\eta\|}c_V\mathrm{Tr}\{D_\mu\left(\eta_{\alpha\beta}V^\alpha V^{\beta\mu}\right)\}$$

$$\xrightarrow[\text{comma}\to\text{semicolon}]{\eta_{\mu\nu}\prec g_{\mu\nu}} \; -\int d^4x\sqrt{\|g\|}\frac{c_V}{2}\mathrm{Tr}\{g_{\mu\alpha}g_{\nu\beta}V^{\mu\nu}V^{\alpha\beta}\}$$

$$+ \int d^4x\sqrt{\|g\|}c_V\mathrm{Tr}\{V^\mu\left(-\mathcal{D}^2g_{\mu\nu} + \mathcal{D}_\mu\mathcal{D}_\nu + V_{\mu\nu} + \Lambda^2g_{\mu\nu}\right)V^\nu\}$$

$$+ \int d^4x\sqrt{\|g\|}c_V\mathrm{Tr}\{\mathcal{D}_\mu\left(g_{\alpha\beta}V^\alpha V^{\beta\mu}\right)\}$$

$$\xrightarrow[\text{gauge invariance}]{\Lambda^2 g_{\mu\nu}\prec R_{\mu\nu}({}^g\Gamma)} \; -\int d^4x\sqrt{\|g\|}\frac{c_V}{2}\mathrm{Tr}\{g_{\mu\alpha}g_{\nu\beta}V^{\mu\nu}V^{\alpha\beta}\}$$

$$+ \int d^4x\sqrt{\|g\|}c_V\mathrm{Tr}\{V^\mu\left(-\mathcal{D}^2g_{\mu\nu} + \mathcal{D}_\mu\mathcal{D}_\nu + V_{\mu\nu} + R_{\mu\nu}({}^g\Gamma)\right)V^\nu\}$$

$$+ \int d^4x\sqrt{\|g\|}c_V\mathrm{Tr}\{\mathcal{D}_\mu\left(g_{\alpha\beta}V^\alpha V^{\beta\mu}\right)\}$$

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

$$= \quad 0$$

adding curvature by gauge invariance

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

$S^1_\Lambda(\eta)$ 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:
$\tilde{S}^0_\Lambda(g, R)\big\rfloor_{R=0} = S^0_\Lambda(\eta)\Big\rfloor_{\Lambda=0}$

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

the SM effective action in curved ST

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

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:

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

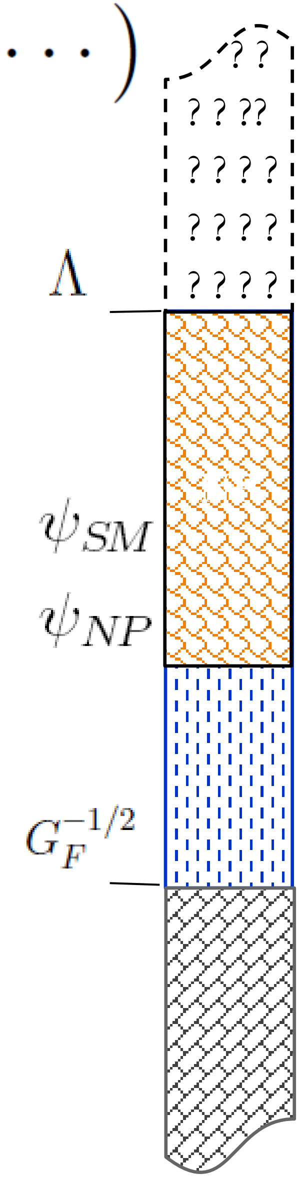
the SM spectrum alone leads to **“repulsive”** gravity!

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

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

the NP particle spectrum

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



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

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 gravitizaton, 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 $\lambda_{HS} H^\dagger H S^\dagger S$ 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:

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

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

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

in a momentum space of dimension $D = 4 - \epsilon$ 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

- $\boldsymbol{E(8) \otimes E(8) \otimes E(8)}$ **gauge theory**
- **Possible** $\boldsymbol{SU(N)}$ **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:

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

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

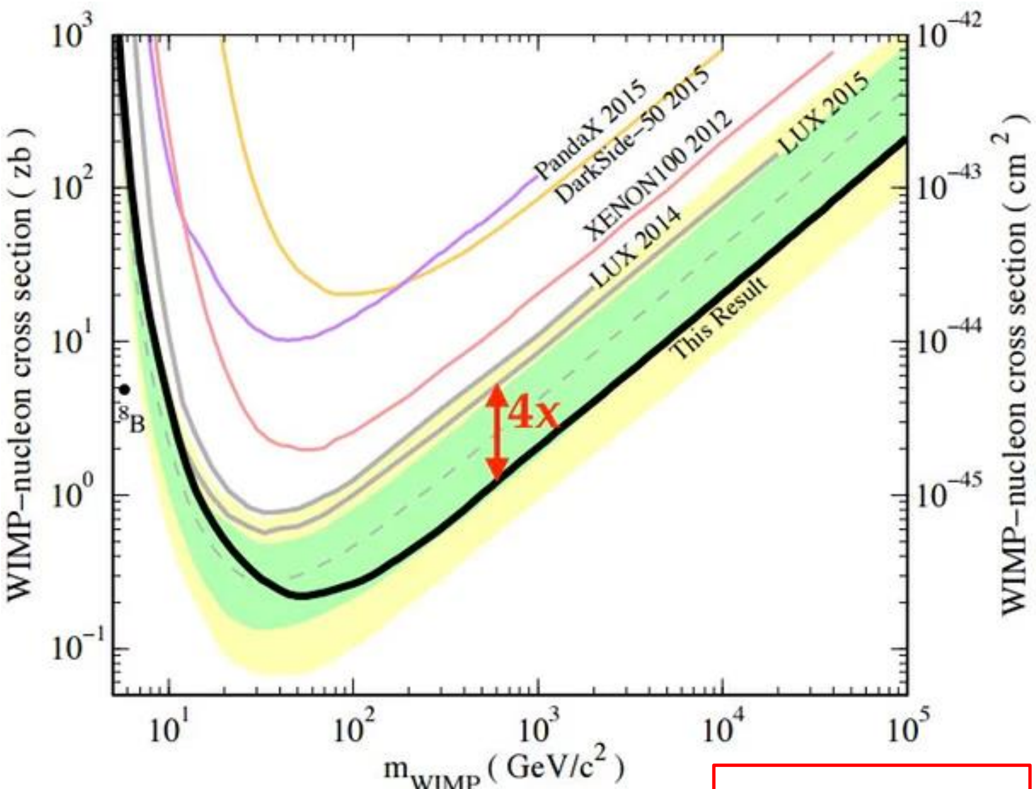
a matter of
$n_b^{NP} - n_f^{NP}$

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

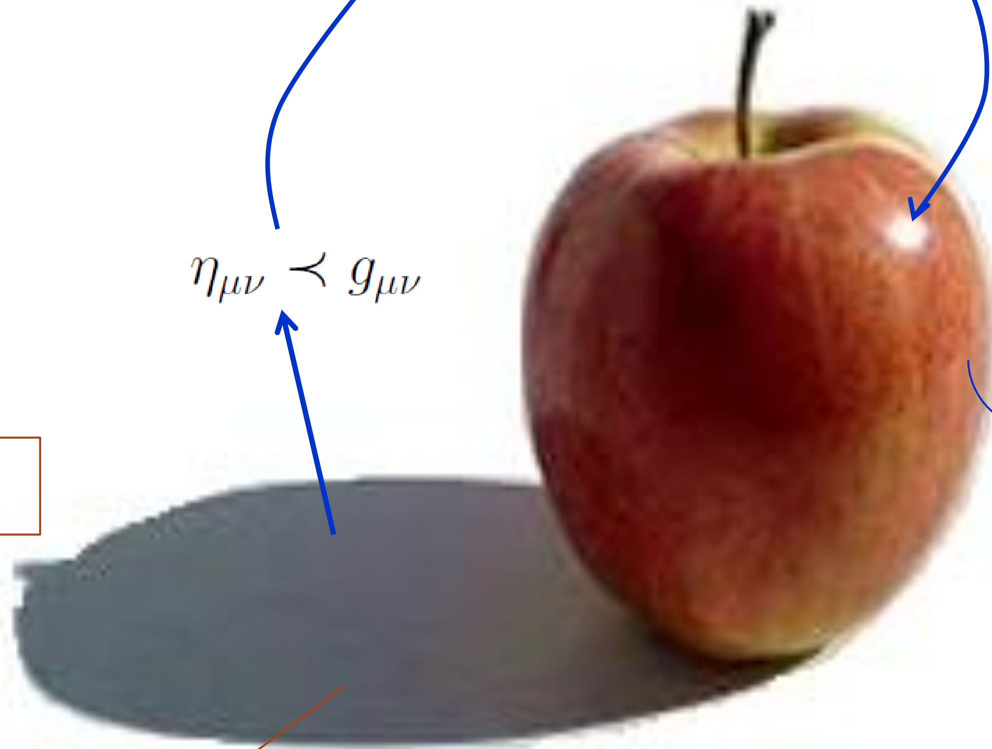
	Extra Dimensions ($\Lambda \simeq$ TeV)	Supersymmetry (Λ : Not Fixed)	Gravitization ($\Lambda \simeq M_{Pl}$)
NP	Necessary	Necessary	Necessary
Bosons-Fermions	Not Fixed	0	$\gtrsim 128\pi^2$
NP-SM Interaction	Necessary	Necessary	Not Necessary
Scale of NP	TeV	TeV	Not Fixed
Nature of Λ	Non-Inertial	Inertial	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

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

SM + NP

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



SM

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

- ✓ natural
- ✓ exact gauge symmetry
- ✓ gravity
- ✓ dark matter
- ✓ inflaton
- ✓ ν-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 [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)

Report number: IZTECH-HEP-03/2016

Cite as: **arXiv:1605.00377 [hep-ph]**