# THE FUTURE

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1. KINDERGARTEN PARTONS

2. HIGGSTERIA

3. DARK MATTER / HIGGS

4. DARK ENERGY / DARKNESS

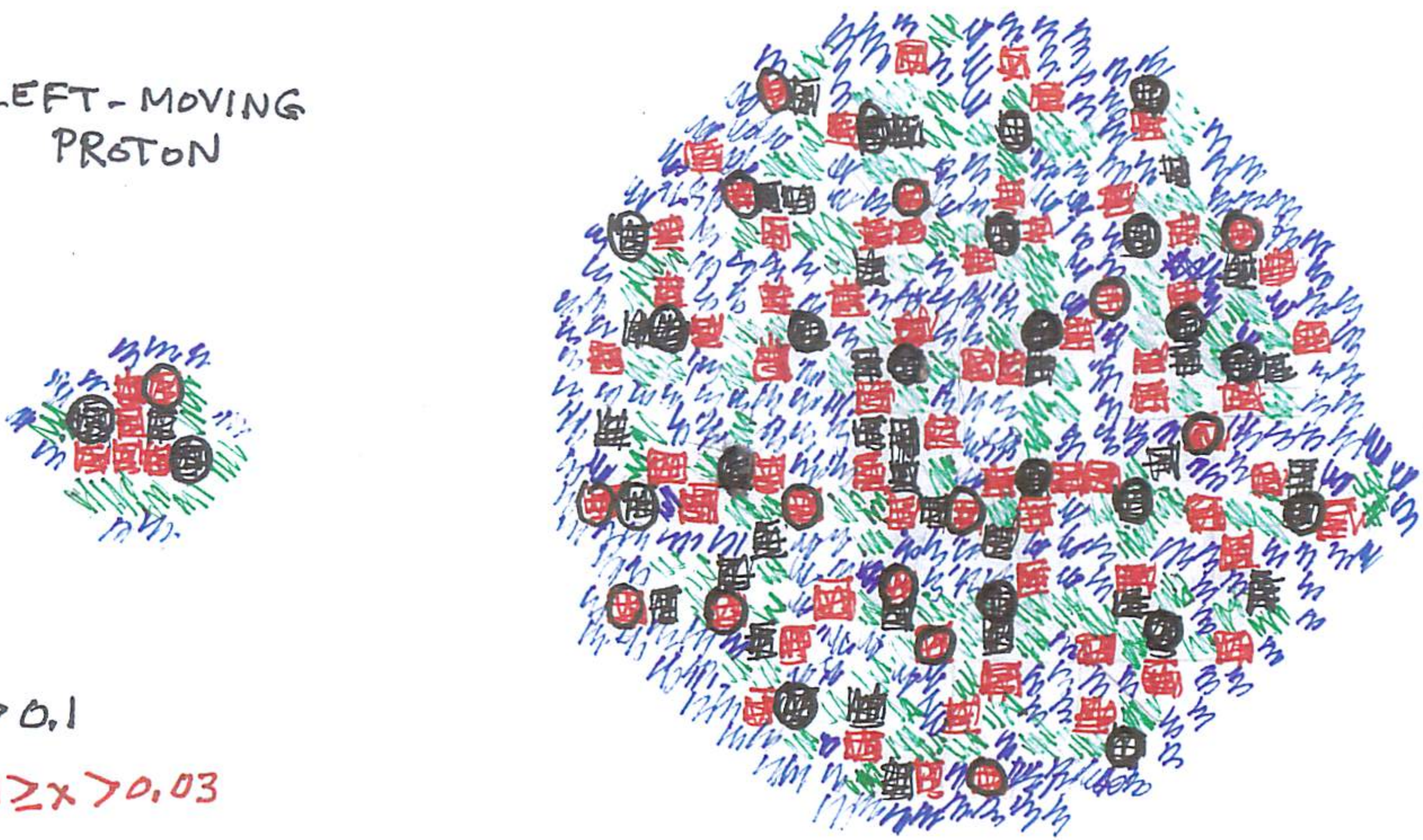
5. COMMENTS

# PIXELIZED HADRONS

## (BEAM'S – EYE VIEW)

LEFT-MOVING PROTON

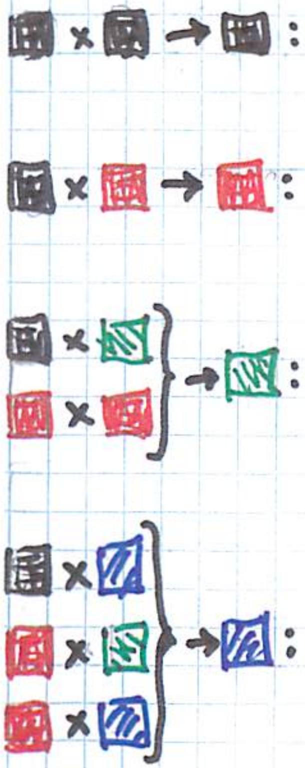
LEFT-MOVING CARBON NUCLEUS



- $X > 0.1$
- $0.1 \geq X > 0.03$
- $0.03 \geq X > 0.01$
- $0.01 \geq X \geq .001$

X = LONGITUDINAL MOMENTUM FRACTION PER NUCLEON

# A PIXELIZED ION-ION COLLISION

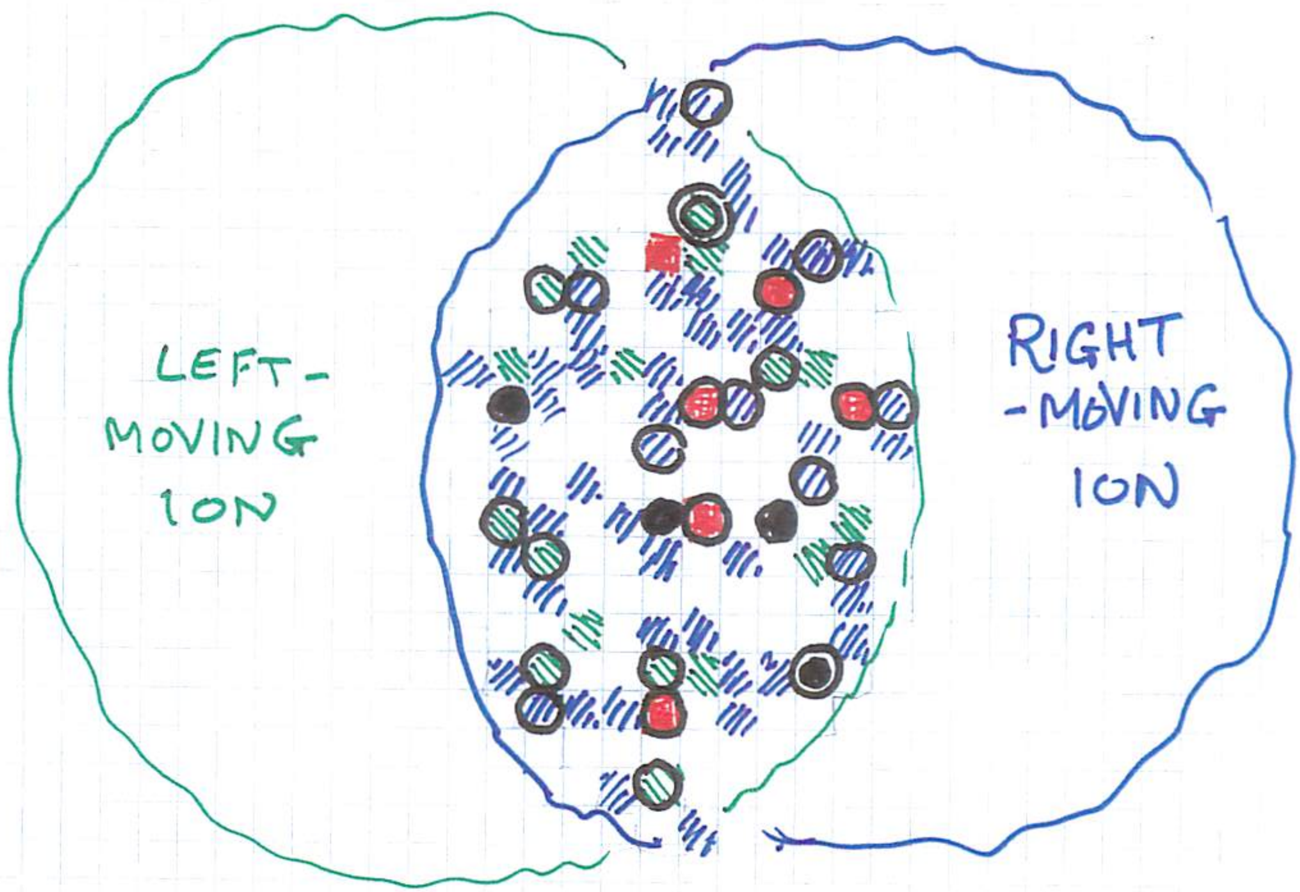


$\sqrt{X_L X_R} \gtrsim 0.1$

$0.1 \gtrsim \sqrt{X_L X_R} \gtrsim 0.01$

$0.01 \gtrsim \sqrt{X_L X_R} \gtrsim 0.001$

$0.001 \gtrsim \sqrt{X_L X_R} \gtrsim 0.0001$



# AN UNUSUAL (PIXELIZED) PP COLLISION

(BEAM'S-EYE VIEWS)

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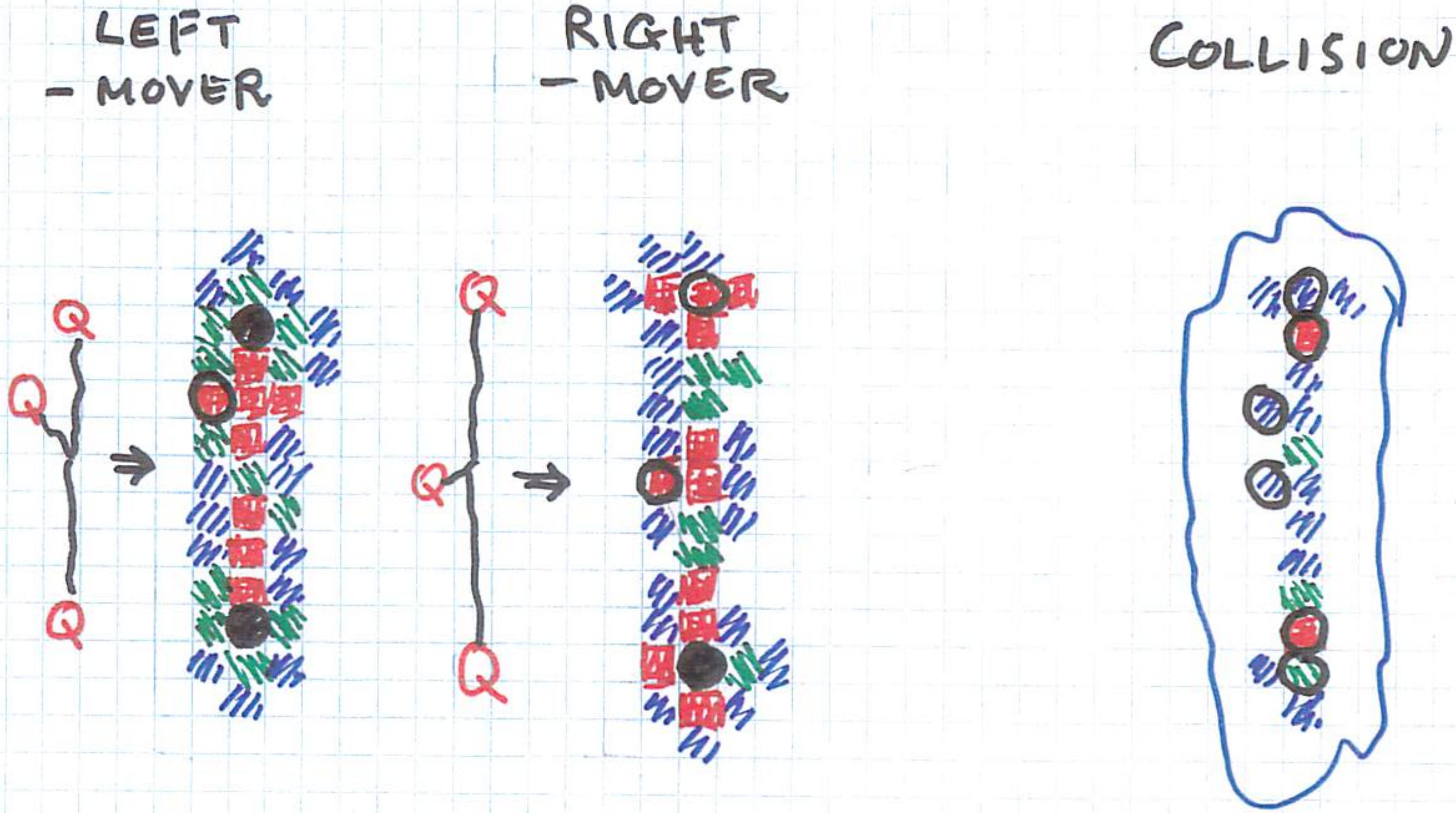


# HIGGSTERIA

**Flavor symmetry** $\equiv SU(6)_L \times SU(6)_R$

**Family symmetry** $\equiv SU(3)_L \times SU(3)_R$

family triplets: $\begin{pmatrix} u \\ c \\ t \end{pmatrix}_{L,R} \begin{pmatrix} d \\ s \\ b \end{pmatrix}_{L,R} \begin{pmatrix} e \\ \mu \\ \tau \end{pmatrix}_{L,R} \begin{pmatrix} \nu \\ \nu \\ \nu \end{pmatrix}_L$

family singlets: $\gamma, g, W^{\pm}_T, Z_T$

**HOW SHOULD WE ASSIGN $h, W^{\pm}_L, Z_L$ ??**

My choice is a nonet:

$$\begin{array}{c|ccc} & u & c & t \\ \hline u & \bullet & \bullet & \bullet \\ c & \bullet & \bullet & \bullet \\ t & \bullet & \bullet & \star \end{array}$$

?

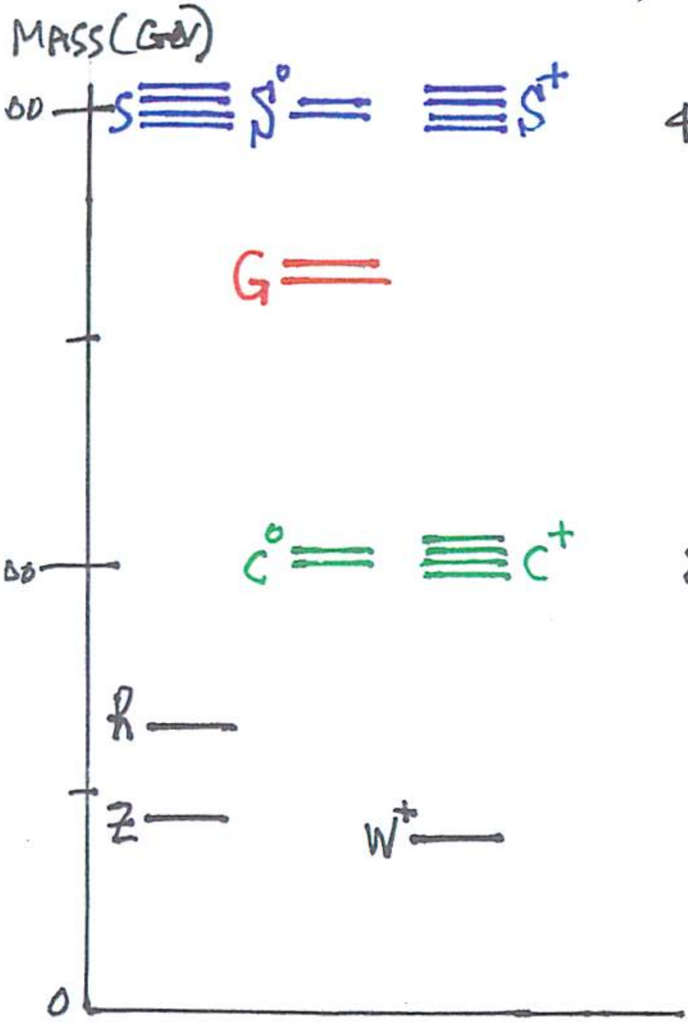
# CONSEQUENCES:

- Family symmetry is spontaneously broken.

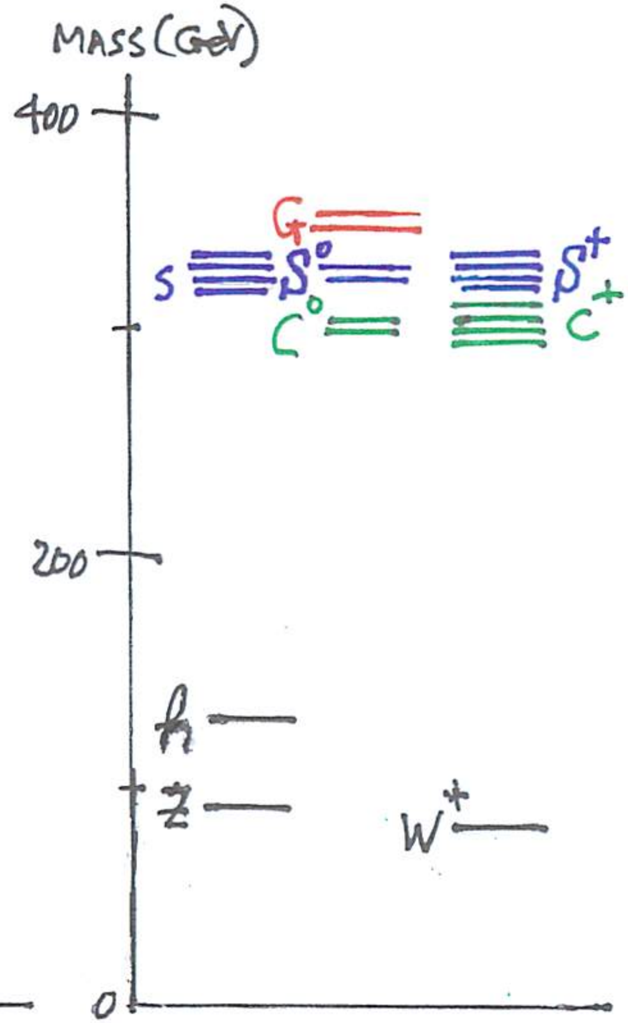
- 32 New states: masses ~ 200-500 GeV (?)

- Decays are overwhelmingly to top-antitop + jets final states.

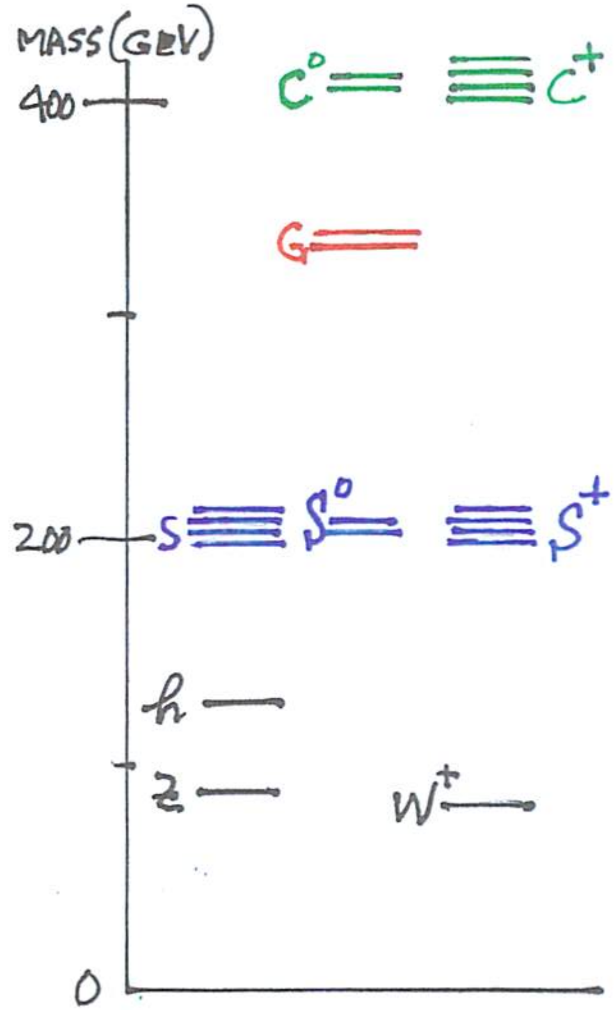
# A HIGGS FAMILY




OPTION A




OPTION B




OPTION C

DECAYS: $C, G \to t\bar{q}$ $\quad S, \mathcal{S} \to \begin{cases} t\bar{q}\,\bar{b}q' \\ b\bar{q}\,\bar{t}q' \end{cases}$ $\quad [q \,\&\, q' = u, d, s, \text{ or } c]$

# THEORY STATUS: INCOMPLETE

- For vanishing CKM mixing, theory is OK.
- For nonvanishing CKM mixing, problems remain:
  - "Parameter of difficulty" is $\left(\frac{m_b}{m_t}\right)^2 |V_{cb}| \sim 3 \times 10^{-5}$.
  - Additional family multiplets are probably needed.

- LHC search phenomenology appears robust — no matter what.

# HOW BIG IS THE HIGGS SECTOR ?

GUT SO(10) ⇒ { 36 Goldstones; Many massive modes }

My present working hypothesis is SO(16)

$$SO(16) \supset SO(10) \times SO(6)$$

SO(10) ↓ GUT SU(5) ↓ Standard-model particles

SO(6) ↓ SU(3) Family?? ↓ Low mass dark matter sector ??

# RAW MATERIAL FOR THE MODEL

$\frac{16 \times 15}{2} = 120$ "Adjoint Higgs'" $\Phi_{[ij]}$

$16 \times 16 = 256$ "Frame Higgs'" $\varphi_i^A$

- "Frame-field" tactic not well-explored (?)
- Motivations: "Rotating mass matrix" [Hong Mo Chan et.al arXiv 1206.0199]

  "Vierbein" in first-order GR

# DARK ENERGY & DARKNESS

GR defines two extreme scales:

$$G_{Newton} \sim \frac{1}{M_{pl}^2} \sim \left(10^{-33}\,cm\right)^2 \qquad\qquad \Lambda \equiv \frac{H^2}{3} \sim \left(10^{28}\,cm\right)^{-2}$$

These induce an intermediate scale:

Dark-energy density $\rho_{DE} \sim H^2 M_{pl}^2 \sim \left[10^{-3}\,cm\right]^{-4}$

Is there another intermediate scale?

"Darkness" (or dark-topology density) $\rho_D \sim H M_{pl}^2 \sim \left[10^{-12}\,cm\right]^{-3}$

# MATTERS OF GRAVITY

(10) Einstein-Hilbert $\quad g_{\mu\nu} \quad S_{EH} \sim M_{pl}^2 \int d^4x \sqrt{g}\, R$

(24+16) Einstein-Cartan $\quad \omega_\mu^{AB} \gamma_A \gamma_B \equiv \omega_\mu \quad e_\mu^A \gamma_A \gamma_5 \equiv e_\mu \quad S_{EC} \sim M_{pl}^2 \int d^4x \, \mathrm{Tr}\, \gamma_5\, e_\wedge e_\wedge R$

(40) MacDowell-Mansouri $\quad A_\mu \equiv H e_\mu + \omega_\mu \quad S_{MM} \sim \frac{M_{pl}^2}{H^2} \int d^4x \, \mathrm{Tr}\, \gamma_5 F_\wedge F$

Topological $\quad$ GR $\quad$ DE

$$S_{MM} \sim \int d^4x \, \mathrm{Tr}\, \gamma_5 \left[ \frac{M_{pl}^2}{H^2} R_\wedge R + M_{pl}^2\, e_\wedge e_\wedge R + H^2 e_\wedge e_\wedge e_\wedge e \right]$$

# THE GAUSS-BONNET (EULER) TERM

$$S_{GB} = \frac{M_{pl}^2}{H^2} \int d^4x \, \mathrm{Tr}\, \gamma_5 R_\wedge R = 2\pi \int dt \left( \frac{dN}{dt} \right)$$

- It is a topological term; it does not contribute to the Einstein equations of motion.
- In FRW cosmology, N is an extensive variable.
- In cosmic voids, $\frac{N}{V} \sim H M_{pl}^2 \sim 10^{39}/\text{liter}$
- In early universe, $\frac{N}{V} \sim M_{pl}^3$ when $T \sim 50\,\text{MeV}$.
- Just outside protons, lead nuclei, neutron stars, $\frac{N}{V} \sim M_{pl}^3$

# WHAT DOES THIS MEAN?

- I don't know
- At best, MacDowell-Mansouri is an effective field theory description, only valid when the distance scale is $> \Lambda_Z^{-1} \sim 10^{-12}$ cm.
- BUT maybe the darkness scale links, via vacuum couplings, to

  $\Lambda_{QCD}$
  Lepton/quark mass scale
  Higgs-sector mass scale (??)
  Dark-matter mass scale

# MASSES & MIXINGS

$m \equiv 7\,\text{MeV}$

| | | |
|---|---|---|
| FIRST GENERATION: | $m_u \lesssim m = 7$ MeV | (2.3 ± 0.6 MeV) |
| | $m_d \lesssim m = 7$ MeV | (4.8 ± 0.5 MeV) |
| | $m_e = m^2/m_\mu = .44$ MeV * | (0.51 MeV) |
| SECOND GENERATION: | $m_c = \sqrt{m\, m_t} = 1.1$ GeV ** | (1.3 GeV) |
| | $m_s = \sqrt{m\, m_b} = 170$ MeV ** | (100 ± 30 MeV) |
| | $m_\mu = \sqrt{m\, m_\tau} = 110$ MeV ** | (106 MeV) |
| CKM MIXING: | $\lvert V_{cb}\rvert = \sqrt{m/m_b} = .040$ ** | (.041) |
| | $\lvert V_{td}\rvert = m/\sqrt{m_b\, m_s} = .0080$ * | (.0081) |
| | $\lvert V_{ub}\rvert = m/\sqrt{m_b\, m_c} = .0032$ * | (.0039) |
| UNITARITY TRIANGLE VERTEX ANGLE: | $\alpha = \frac{\pi}{2}$ | (89° ± 4°) |

# COMMENTS

1. Pay more attention to the family problem.
2. Are there (LHC-accessible) Higgs families?
3. SO(10) GUT already implies a big Higgs sector.
4. Should family symmetry be gauged?
5. Is there a "dark Higgs" subsector?

   "Dark gluons"

   "Dark confinement"

6. Third generation masses ⇔ GUT physics ?

$m_t$ : $10 \times 10 \times (5)_{Higgs}$

$m_b, m_\tau$ : $\overline{10} \times 5 \times (5)_{Higgs}$

$m_{Dirac\,\nu}$ : $1 \times \overline{5} \times (5)_{Higgs}$

7. $1^{st}$ & $2^{nd}$ generation masses & mixings depend on a low mass scale (e.g. 10–100 MeV)?

8. Does that low mass scale (& $\Lambda_{QCD}$) have something to do with "darkness"?

9. Never give up.

# FUTURE FACILITIES

- LHC discovery potential at low mass scales is still high.
- ILC looks very attractive.
- Dark-matter sector may { be complex.
  contain low-mass states.
- Think big ($\gtrsim 100$ TeV) – now!
- In all this, QCD remains of central importance.