Darkness = property of gravitational vacuum, with scale (in empty space) $\sim 10^{13}$ cm.

Its relevance depends upon choice of GR descriptive language.
Metric (E.H) Gravity

\[ \mathcal{L} = \frac{1}{2} \nabla^a \nabla_b R^{b}_{\ a} \]

First order (gauge) Gravity (EC): 

\[ \mathcal{L} = \frac{1}{2} \text{Neer} R \]

\[ R = R_{EC} \]
MacDowell Mansouri Extension of EC:

\[ Y = \frac{M^2}{\Lambda} FF \quad A = \begin{pmatrix} e \\ \omega \end{pmatrix} \]

\[ F = \begin{pmatrix} e & e & e & e & e \end{pmatrix} \]

Decomposition of MM to EC:

\[ Y = \frac{M^2}{\Lambda} \left[ RR + \Lambda e e R + \Lambda^2 e e e e e e \right] \]
Important Features of mm:

- It is a gauge theory like QED, QCD, and EW.

- \( x \) is quadratic in \( F \).

- But it is E-B-like (not \( E^2 - B^2 \)-like).

- Leading term is topological:

\[
\int d^4x \left( \frac{\bar{\Psi} i \gamma^\mu \partial_\mu \Psi}{16\pi^2} \right) = \text{det} (2\pi \text{det} D)
\]

- Darkjets

\[
\Psi^0(\sqrt{m^2} + iRR) = \text{det} \left( 2\pi \text{det} D \right)
\]
How **DARKNESS** **BEHAVES**: 

In FRW expanding universe:

\[ N(t) \sim \frac{M_{\text{pl}}^2}{V(t)} \left( \frac{\dot{a}}{a} \right)^3 \]

Nowadays, \( \left( \frac{\dot{a}}{a} \right) \approx 1 \) \( \Rightarrow \) \( n \approx (M_{\text{pl}}^2 \mu N^{1/2}) \approx 10^{39} \text{ cm}^{-3} \)

("in the future")

In the past, \( m(t) \) was much larger
When \( T \sim 50 \text{ MeV} \) \( m(t) \sim M_{\text{pl}}^3 \)

"QCD" (Scale Zeldovich) \( \leftrightarrow \) limit of validity of MN description

Sources:

- "Sphere of influence"
- Newton
- de Sitter

Nuclear matter

\[ m \sim n_0 \left( \frac{P_0}{\rho} \right)^{1/2} \]

\[ m_0 \sim M_{\text{pl}}^2 \]

\[ m \text{ at surface} \sim M_{\text{pl}}^3 \]
Note: Total amount of darkness in universe dominated by matter:

\[ \text{Baryon} \sim 10^{80} \]
\[ \text{Darkness/nucleon} \sim 10^{60} \]
\[ \Rightarrow 10^{140} \]

De Sitter density \times Volume of universe (inside the horizon)

\[ \sim (10^{39} \text{ cm}^{-3}) \times (10^{28} \text{ cm})^3 \sim 10^{123} \]
Is Darkness = Horizon Entropy?
Newtonian Darkness Flow

\[ P \sim \frac{M^2}{\Lambda^2} \sqrt{\det \Pi} \]

\[ \Pi = \frac{M^2}{\Lambda^2} \eta \]

\[ T_{ij} = \eta \partial_i \phi \]

\[ g_{ij} = \eta \partial_i \phi \]
Comments:

- Is the darkness scale related to $\Lambda_{\text{QCD}}$?
- $g/\ell$ mass scale?
- Dark-matter mass-scale?
- QCD/EW/Higgs vacua vs grav. vacuum.
VOIDS

The Usual Definition:  The Suggested Definition

DENSITY CONTRAST  Riemann Curvature

BEFORE \((\alpha h) \ll 1\)  AFTER \((\alpha h) \gg 1\)
RIEMANN CURVATURE

\[ R_{\mu \nu} = \frac{GM}{r^3} \left( \begin{array}{ccc}
2 & -1 & -1 \\
-1 & 2 & -1 \\
-1 & -1 & 2 \\
\end{array} \right) \]

Schwarzschild

\[ R_{\mu \nu} \sim \Lambda \left( \begin{array}{ccc}
1 & 0 & 0 \\
0 & 1 & 0 \\
0 & 0 & 1 \\
\end{array} \right) \]
de Sitter

THE NEWTONIAN LIMIT

Tidal tensor: \( T_{ij} = \nabla_i \nabla_j \phi \)

If \( \text{Tr} \ T^2 \gg \Lambda \), Matter

If \( \text{Tr} \ T^2 \ll \Lambda \), de Sitter Void
THE SUGGESTION

• Locate the boundary surface in LSS simulations

• Learn by doing

• Is evolution of boundary surface sensitive to quintessence models?

• Study motion of "test particles" in voids

• Apply what is learned to real life (much harder)
QCD at the LHC

- Heavy Ions (Pb)
- Fixed Target (C, N, Al, Fe)

Before

After

bij
THE DECAY OF "NOTHING"

diagram:

- Red arrow indicating direction
- Blue grid-like structure
- Dotted line
- "Soft πmesons + photons"
Huygen's principle tells the story

- Pulse thickness is ~ nuclear diameter
- The pulse is noisy

- How much energy is emitted?
- What is the multiplicity of emitted quanta?
EM Radiation:

\[ \text{Energy} = \int d^3r \left( \frac{E^2}{2} \right) \sim \begin{cases} \frac{\hbar^2 k}{R_{\text{nucleus}}} & \text{(coherent)} \\ \frac{\hbar k}{R_{\text{quark}}} & \text{(incoherent)} \end{cases} \]

Momentum \sim \begin{cases} \frac{1}{R_{\text{nucleus}}} & \text{coherent} \\ \frac{1}{R_{\text{quark}}} & \text{incoherent} \end{cases}
Pion Radiation in Chiral Limit ($m_{\pi} = 0$)

Energy $\sim \Delta (F_{\pi}^{+} \cdot \frac{4}{3} \pi R^{3} \frac{N_{e}}{m_{e}})$

$\sim m_{A} A$ incoherent (conceives)

$\sim m_{A}$ A incoherent (conceives)

$\Delta F_{A}$ = change in vev due to presence of nuclear matter ("bag model")
Real life:

How does $m \neq 0$ affect the answer?

"Coherent" piece is suppressed?

"Ouch" piece is robust?

Best answer:

Do the experiment & find out.
The experiment:

- Beam Pipe
- Ions
- Gas or Solid Target
- Detector (tracks)

End View

Side View

- For every bunch crossing ($\Delta t = 200\text{ nsec}$), count tracks.
- Location: Beam abort channel? Halo of circulating beam?
VACUUM ENGINEERING

WHAT DOES ONE LEARN??

- Nothing of importance?
- Something about chiral QCD vacuum?
- Link with cosmic-ray 2oo events?

Tools:
- Multiplicity dist
- Momentum spectra
- DCC ??
- HBT ??
- ????