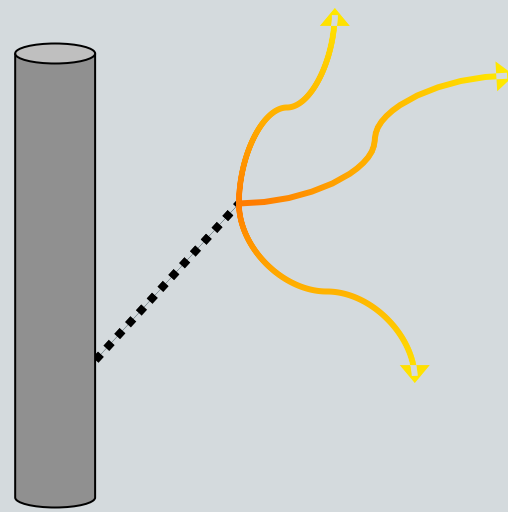
No LIGHT from LIGHT Dark Strings



ASU/Tufts Cosmic Strings Workshop
February 4, 2014

Andrew Long
@ ASU

"Can we find evidence of cosmic strings w/ astrophysics?"

- Non-gravitational probe of cosmological relics (e.g., radio bursts, gamma ray, cosmic ray, neutrino, CMB spectral distortions) [Danni's talk]

[Srednicki & Theisen (1987); Aharonian, Bhattacharjee, & Schramm (1992); Darmour & Vilenkin (1997); Vachaspati (2009); Sabancilar (2009); Steer & Vachaspati (2011); Cai, Sabancilar, Steer, & Vachaspati (2012); Lunardini & Sabancilar (2012); Tashiro, Sabancilar, & Vachaspati (2012)]

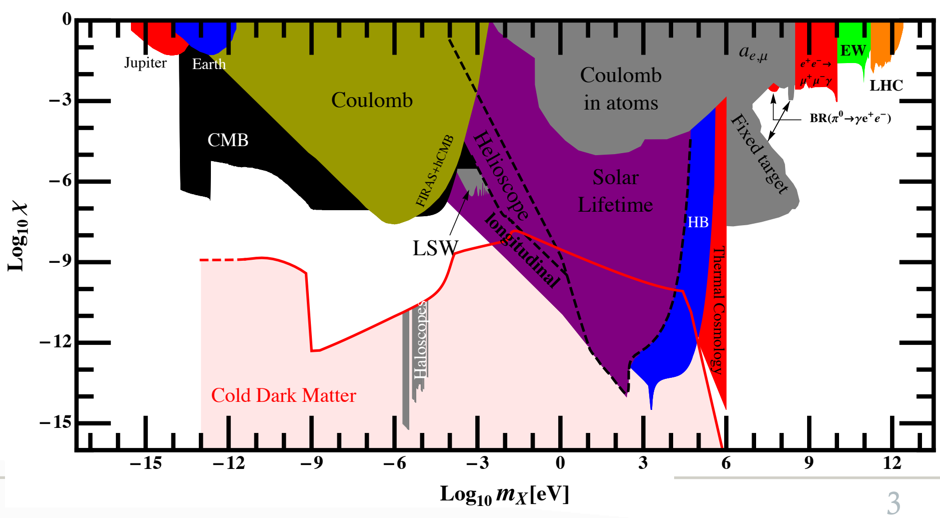
- Linear scalar-to-string coupling enhances particle emission (from cusps & kinks) [Eray's talk]
- Different literature contains both lower bounds and upper bounds on the string tension (lighter strings more abundant, heavier strings more strongly coupled to scalar)
- String couples to SM via dilaton / moduli – why not Higgs?

“Can we constrain BSM physics w/ strings (via astrophysics)?”

- TeV-scale hidden sector models w/ broken U(1)’s – motivated by dark matter, electroweak phase transition, Higgs physics

- Minimal – only two

interactions w/ SM:



- Goal – extend or compliment laboratory constraints w/ cosmic strings

[Jaeckel (2013)]

SM-to-Dark String Interactions

Z-Boson

$$S_{\rm int} = \frac{g_{\rm Z}^{\rm str}}{2} \frac{\eta^2}{\mu} \int d\sigma^{\mu\nu} Z_{\mu\nu}(X^\mu)$$

Higgs Boson

$$S_{\rm int} = g_{\rm H}^{\rm str} \eta \int d\sigma \, d\tau \, \sqrt{-\gamma} \, \phi_H(X^\mu)$$

Aharonov Bohm

$$\text{AB Phase:} \qquad \theta_i = q_i \Theta \qquad \text{with} \qquad \Theta \equiv -2 \frac{\cos\theta_W \sin\epsilon}{g_{\rm X}}$$

[Hyde, AL, Vachaspati (2012)]

SM-to-Dark String Interactions

electroweak scale

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electroweak scale

functions of Higgs portal and gauge-kinetic mixing couplings

Aharonov Bohm

AB Phase: $\theta_i = q_i \Theta$ with $\Theta \equiv -2\frac{\cos\theta_W \sin\epsilon}{g_{\rm X}}$

[Hyde, AL, Vachaspati (2012)]

Z Boson Emission

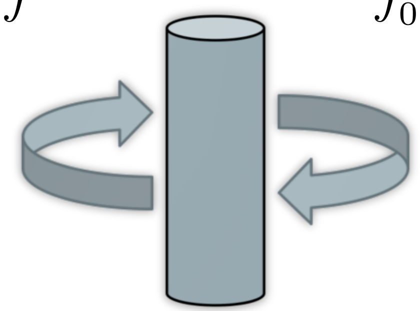
The dark string provides a source current for the Z-boson field. . .

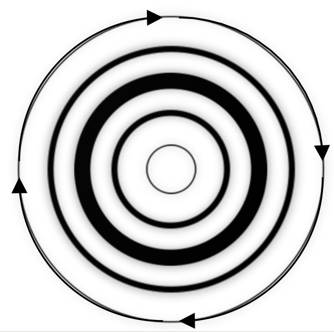
$$\Box Z^\mu + M^2 Z^\mu = \mathcal{J}^\mu$$

$$\mathcal{J}^\mu(t,\mathbf{x}) = \frac{g_Z^{\rm str}}{2}\frac{\eta^2}{\mu}\,\partial_\nu \int d^2\sigma^{\mu\nu}\ \delta^{(4)}(x - X(\tau,\sigma))$$

. . . but there is no radiation
[Alford & Wilzcek (1989)]

$$k_\mu \int d^2\sigma^{i\mu} e^{ik\cdot X} \ = \ \int_0^L d\sigma_+ k\cdot b' e^{ik\cdot b/2} \times \cdots \ = \ \int_0^L d\sigma_+ \frac{d}{d\sigma_+} e^{ik\cdot b/2} \ = \ 0$$





Higgs Emission

$$S_{\rm int} = g_{\rm H}^{\rm str}\eta \int d\sigma\, d\tau\, \sqrt{-\gamma}\, \phi_H(X^\mu) \quad \Rightarrow \begin{cases} P_{\rm cusp} = \Gamma_c (g_{\rm H}^{\rm str})^2 \eta^2 (mL)^{-1/2} \\ P_{\rm kink} = \Gamma_k (g_{\rm H}^{\rm str})^2 \eta^2 \\ P_{\rm grav} = \Gamma_g G\mu^2 \end{cases}$$

[Eray's talk]

Higgs Decay Chain

$$H \;\rightarrow\; b\bar{b} \;\rightarrow\; \text{hadronic cascade (pions)} \;\rightarrow\; \text{VHE } \gamma\text{-rays} \;\rightarrow\; \text{EM cascade}$$

Evidenced by diffuse gamma ray flux with characteristic E^{-2} spectrum

Vachaspati (2009):

Higgs emission (from cusps) imposes lower bound on string tension

Lunardini & Sabancilar (2012):

dilaton emission (from kinks) imposes upper bound on string tension

Network Evolution

<u>Scaling</u>

$$dn = \frac{\zeta}{3\sqrt{3}} \, \frac{\sqrt{t_{eq}}}{t^2 \, (L + \Gamma t)^{5/2}} dL \qquad \text{(R-era relic loops)}$$

[Blanco-Pillado, Olum, & Shlaer (2013)]

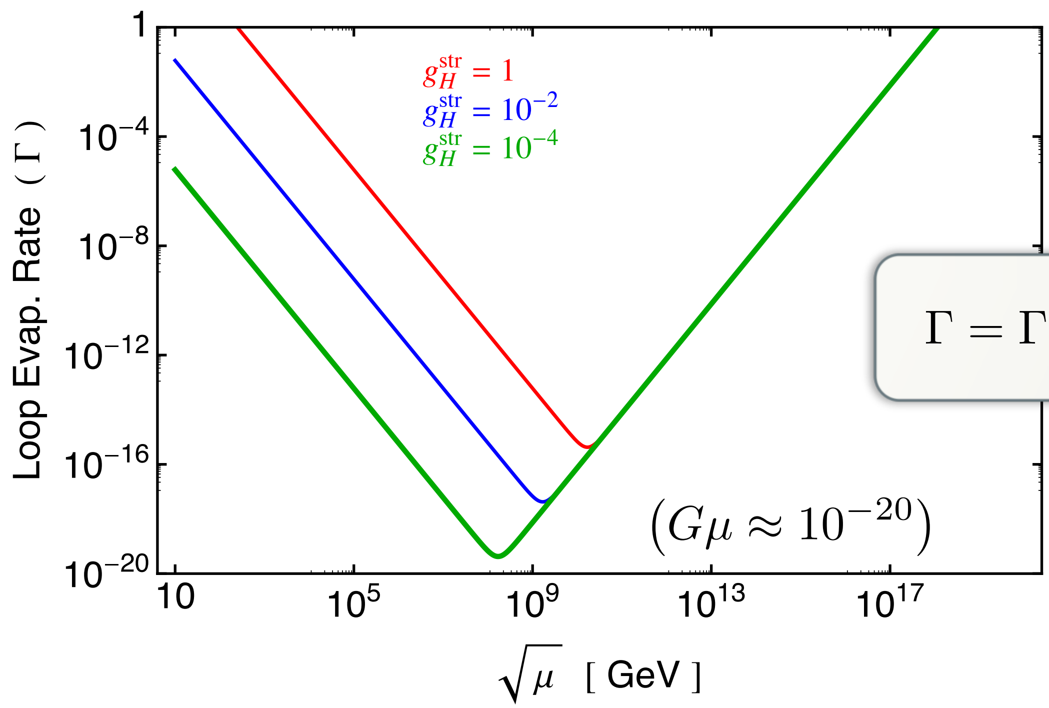
<u>Loop Evaporation</u>

$$\frac{dL}{dt} = -\frac{P_{\text{grav}} + P_{\text{kink}}}{\mu} = -\Gamma \, t$$

$$\Gamma = \Gamma_g G\mu + \Gamma_k (g_{\text{H}}^{\text{str}})^2 \, \frac{\eta^2}{\mu}$$

Large tension ➔ loops shrink quickly via gravity wave emission
Small tension ➔ loops shrink quickly via Higgs emission

Network Evolution



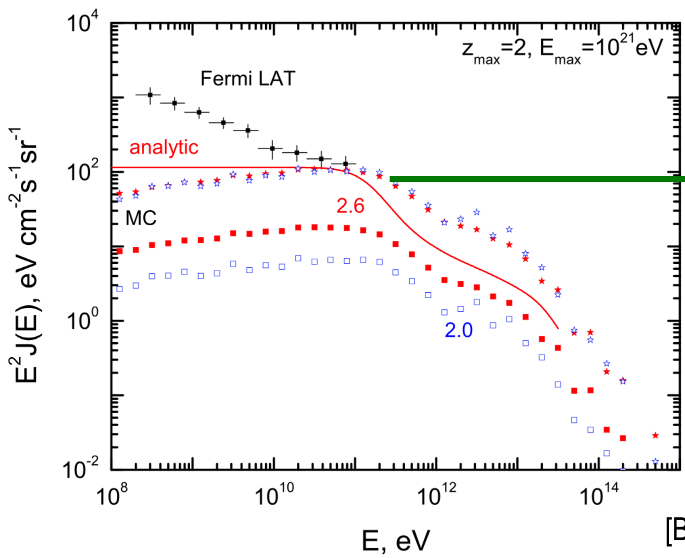
$$\Gamma = \Gamma_g G\mu + \Gamma_k (g_{\rm H}^{\rm str})^2 \frac{\eta^2}{\mu}$$

$$\mu_{\rm cross} = \sqrt{\frac{\Gamma_k}{\Gamma_g G}}\, g_{\rm H}^{\rm str}\eta \;\simeq\; (1\times 10^{10}\ {\rm GeV})^2 \left(\frac{\Gamma_k}{1}\right)^{1/2} \left(\frac{\Gamma_g}{100}\right)^{-1/2} \left(\frac{g_{\rm H}^{\rm str}}{1}\right)$$

Diffuse Gamma Ray Flux

Fermi-LAT does not see EM cascade (E^{-2} spectrum)
➔ Places an upper bound on the energy injected into the cascade

$$\omega_{\rm cas} = \frac{f_\pi}{2}\int_{t_{eq}}^{t_0} dt' \frac{1}{(1+z(t'))^4}\int_0^\infty dL \times \frac{dn_L}{dL} \times P_{\rm kink}$$

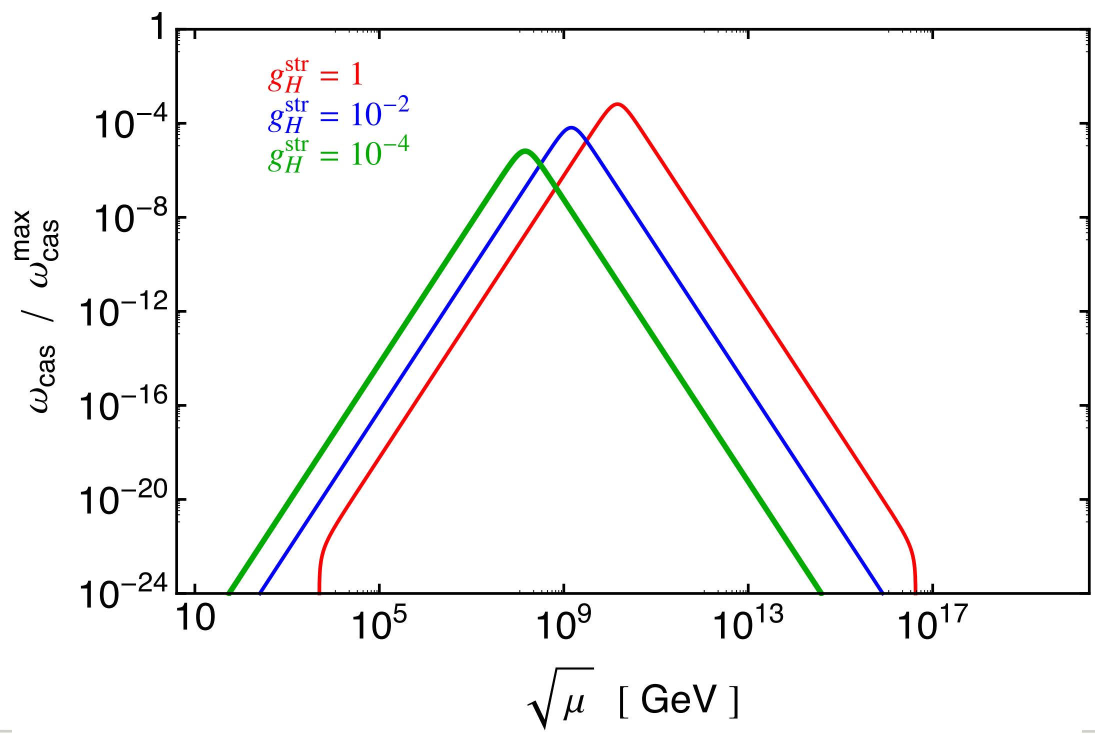


[Berezinsky, et. al. (2010)]

$$\omega_{\rm cas}^{(\rm max)} \approx 5.8 \times 10^{-7}\,\frac{\rm eV}{\rm cm^3} \qquad (\text{Fermi} - \text{LAT})$$

Diffuse Gamma Ray Flux

$$\omega_{\rm cas} = (f_\pi \zeta \Gamma_k) \frac{(g_{\rm H}^{\rm str})^2 \eta^2}{(\Gamma_g G\mu + \Gamma_k \frac{(g_{\rm H}^{\rm str})^2 \eta^2}{\mu})^{3/2}} \frac{t_{eq}^{1/2}}{t_0^{5/2}}$$



Diffuse Gamma Ray Flux

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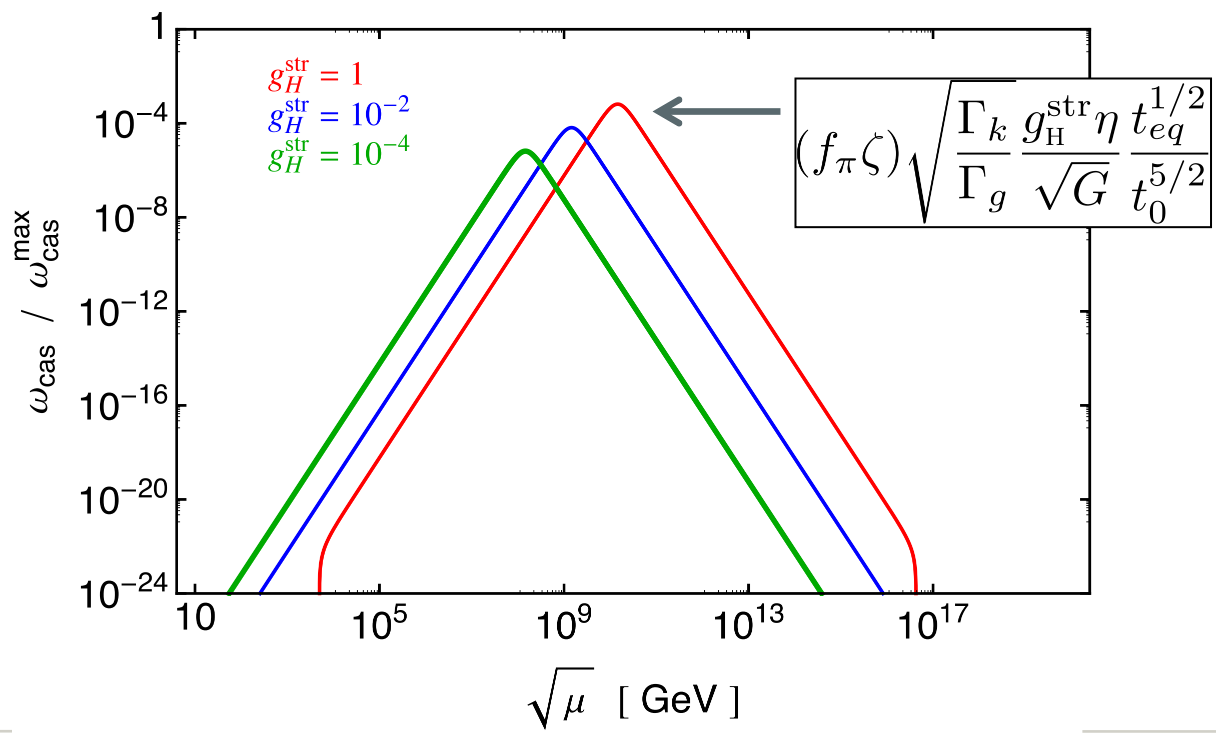
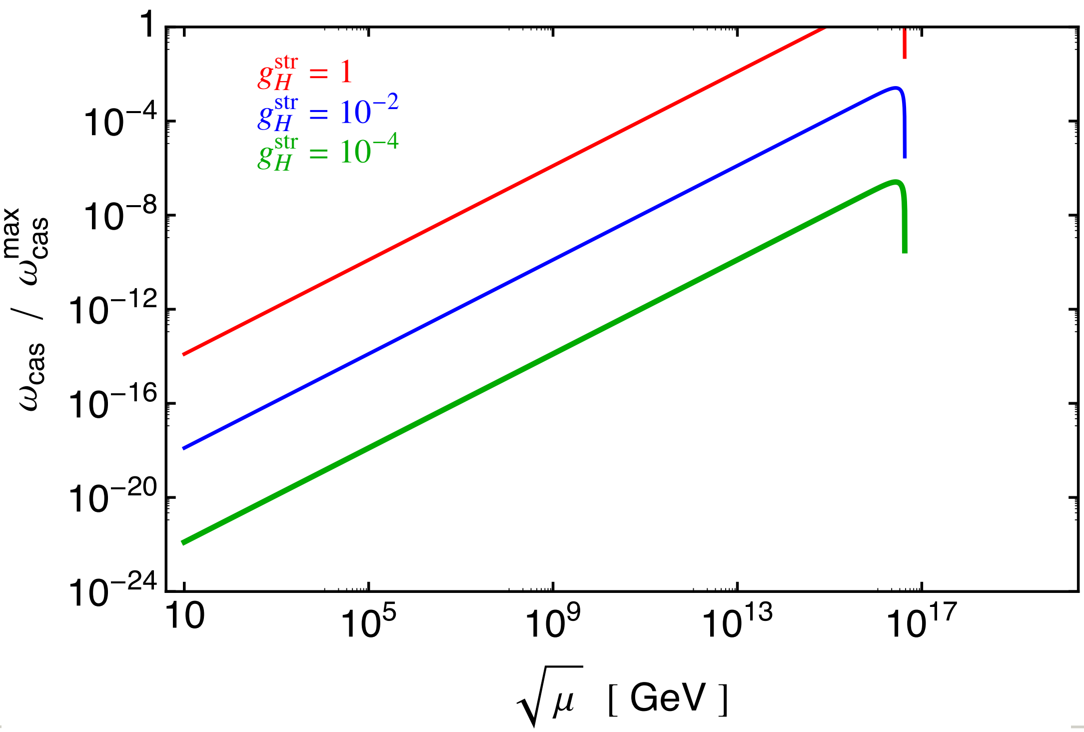


Diffuse Gamma Ray Flux

$$(g_{\rm H}^{\rm str})^2\eta^2 \;\rightarrow\; G\mu^2$$

$$\omega_{\rm cas} \;=\; (f_\pi \zeta \Gamma_k)\frac{G^{-1/2}\mu^{1/2}}{(\Gamma_g+\Gamma_k)^{3/2}}\frac{t_{eq}^{1/2}}{t_0^{5/2}}$$



Conclusion

Null Result

→ No emission of spin-1 particle (Z-boson)

→ Higgs emission does not saturate diffuse gamma ray flux

→ Neither an upper bound nor lower bound on the tension

→ Particle radiation becomes significant at a *high scale* ($G\mu_{cross} \sim 10^{-20}$ even though $\eta \sim 100$ GeV). Here, it is not true that "lighter strings are more abundant."

Take Home / Bring Back

1. There are compelling reasons to study **light (dark) strings**
   -- connection /w particle physics, e.g., dark matter, Higgs physics

2. Requires **non-gravitational** interactions
   -- Introduces a model dependence but allows for alternate verification
   -- E.g., dark matter [Jeannerot, Zhang, & Brandenberger (1999); Hindmarsh, Kirk, & West (2013)] , CMB distortion [Tashiro, Sabancilar, Vachaspati (2012)]

3. The search for light relics is **not a new frontier**,
   -- analogous to DM indirect detection,
   -- but it's worth revisiting in light of new experiments (Ice Cube),
   -- and it requires further work (e.g., backreaction on kinks / cusps)

4. "Probing particle physics from the **bottom-up** with cosmic strings"

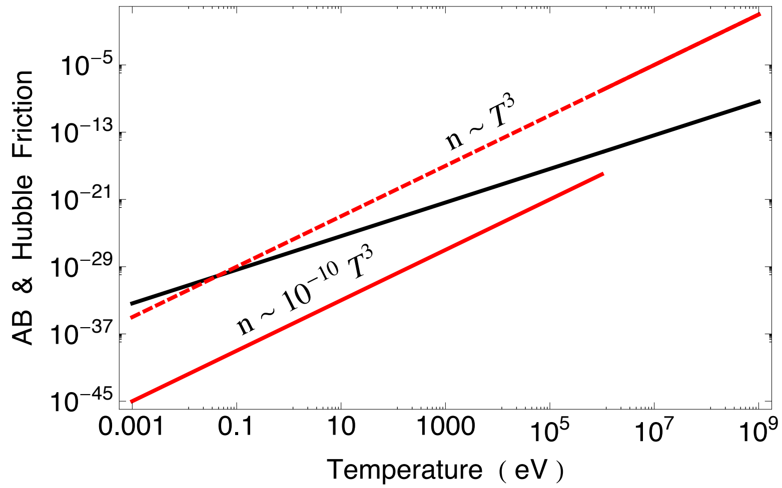
Friction

Ahoronov-Bohm scattering induces friction w/ SM plasma:

$$\mathbf{f}(t) \sim -\sin^2(\pi\phi_{\rm AB})\; n_e(t)\; \mathbf{v}$$

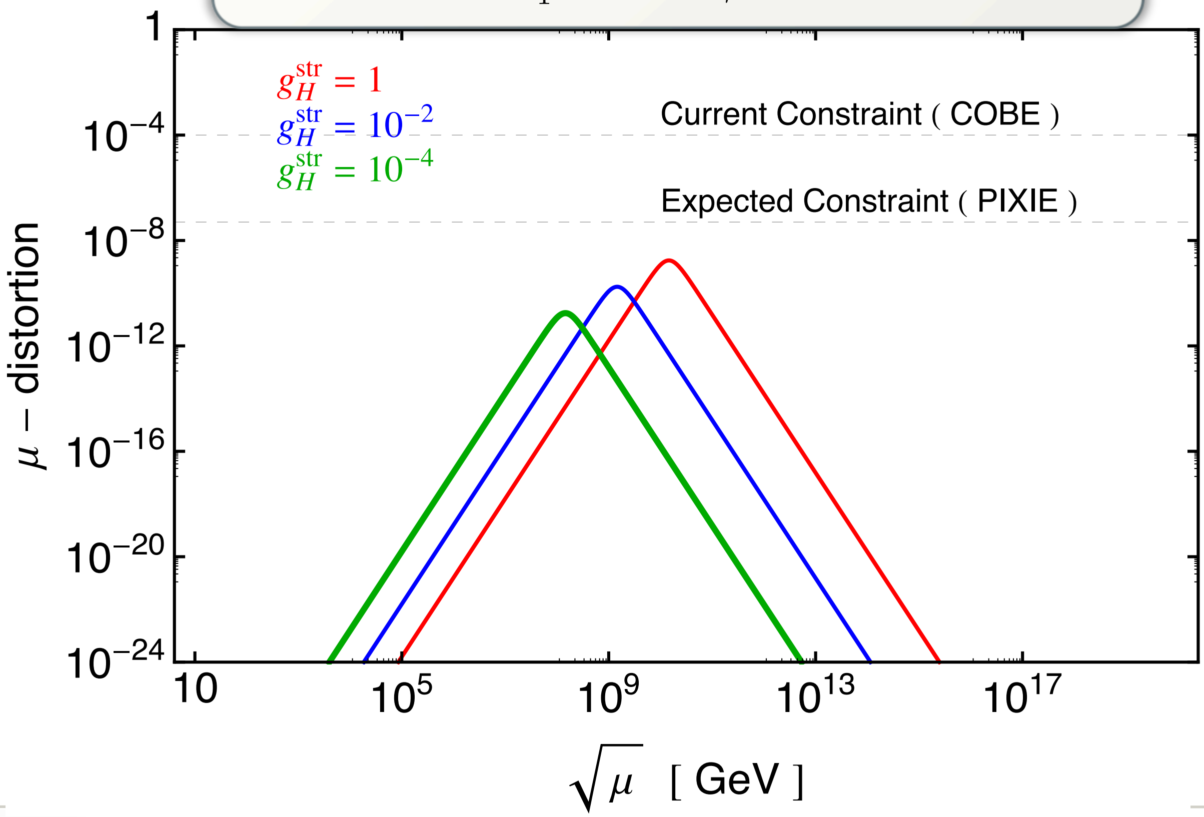
$$T_* \approx \frac{\mu}{M_P}\frac{1}{\sin^2(\pi\phi_{\rm AB})} \approx 0.1\ \text{eV}\left(\frac{\sqrt{\mu}}{10\ \text{TeV}}\right)^2$$

Strings evolve freely after e+e- annihilation

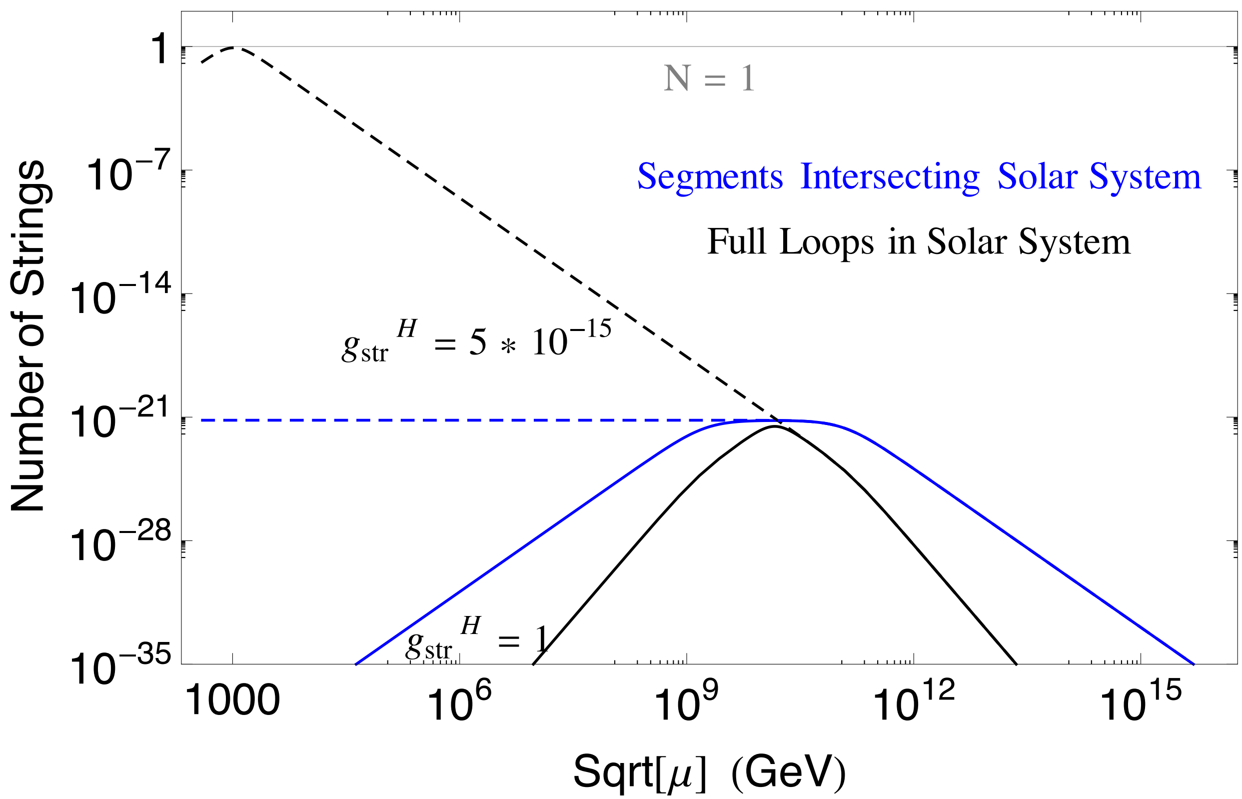


Spectral Distortion

$$\mu_{\rm dist.} = 1.4 \int_{t_1}^{t_2} dt\, \frac{e^{-z/z_{\rm DC}}}{\rho_\gamma} \int dL\, \frac{dn_L}{dL}\, P_{\rm kink}$$



Local Loops



N = 1
Segments Intersecting Solar System
Full Loops in Solar System
$g_{str}{}^{H} = 5 * 10^{-15}$
$g_{str}{}^{H} = 1$
Number of Strings
1
10^{-7}
10^{-14}
10^{-21}
10^{-28}
10^{-35}
1000
10^{6}
10^{9}
10^{12}
10^{15}
Sqrt[μ] (GeV)

Minimum Loop Size