Particle Radiation and Cosmic Rays from Cosmic Strings

Eray Sabancilar
Physics Department, Arizona State University,
Tempe AZ.

2014 ASU-Tufts Joint Workshop on Cosmic Strings
Tempe, AZ,
February 4th, 2014.

Particle Radiation

Volume 189, number 4 PHYSICS LETTERS B 14 May 1987

NONGRAVITATIONAL DECAY OF COSMIC STRINGS

Mark SREDNICKI and Stefan THEISEN [1]

Department of Physics, University of California, Santa Barbara, CA 93106, USA

Received 28 July 1986; revised manuscript received 21 November 1986

We investigate the decay of loops of cosmic string via radiation of nongravitational energy. We show that emission of particles other than gravitons and Goldstone bosons is not significant. We use methods which are considerably more rigorous than those used in the past to draw similar conclusions.

Thank you!

Particle Radiation

Volume 189, number 4 PHYSICS LETTERS B 14 May 1987

NONGRAVITATIONAL DECAY OF COSMIC STRINGS

Mark SREDNICKI and Stefan THEISEN [1]
Department of Physics, University of California, Santa Barbara, CA 93106, USA

Received 28 July 1986; revised manuscript received 21 November 1986

We investigate the decay of loops of cosmic string via radiation of nongravitational energy. We show that emission of particles other than gravitons and Goldstone bosons is not significant. We use methods which are considerably more rigorous than those used in the past to draw similar conclusions.

VOLUME 78, NUMBER 12 PHYSICAL REVIEW LETTERS 24 MARCH 1997

Cosmic Strings and the String Dilaton

Thibault Damour
Institut des Hautes Etudes Scientifiques, F-91440 Bures sur Yvette, France
and DARC, CNRS-Observatoire de Paris, F-92195 Meudon, France

Alexander Vilenkin
Institute of Cosmology, Department of Physics and Astronomy, Tufts University, Medford, Massachusetts 02155
(Received 3 October 1996)

The existence of a dilaton (or moduli) with gravitational-strength coupling to matter imposes stringent constraints on the allowed energy scale of cosmic strings, η. In particular, superheavy gauge strings with $\eta \sim 10^{16}$ GeV are ruled out unless the dilaton mass $m_\phi \gtrsim 100$ TeV, while the currently popular value $m_\phi \sim 1$ TeV imposes the bound $\eta \lesssim 3 \times 10^{11}$ GeV. Some nonstandard cosmological scenarios which can avoid these constraints are pointed out. [S0031-9007(97)02779-8]

Scalar Particle Radiation

- **Quadratic coupling:** **Srednicki, Theisen '87** $\longrightarrow$ Not significant!

$$\mathcal{L} \sim \lambda \int d^2\sigma \sqrt{-\gamma}\, \varphi^2. \tag{1}$$

Scalar Particle Radiation

- **Quadratic coupling:** **Srednicki, Theisen '87** $\rightarrow$ Not significant!

$$\mathcal{L} \sim \lambda \int d^2\sigma \sqrt{-\gamma}\, \varphi^2. \tag{2}$$

- **Linear coupling:** Dilaton $(\alpha = 1)$ **Damour, Vilenkin '97** ,
  Moduli $(\alpha \gtrsim 1)$ **ES '09; Berezinsky, ES, Vilenkin '10; ES, Lunardini '12**

$$\mathcal{L} \sim \frac{\alpha}{m_p} \mu \int d^2\sigma \sqrt{-\gamma}\, \varphi. \tag{3}$$

Scalar Particle Radiation

- **Quadratic coupling:** **Srednicki, Theisen '87** $\rightarrow$ Not significant!

$$\mathcal{L} \sim \lambda \int d^2\sigma \sqrt{-\gamma}\, \varphi^2. \tag{4}$$

- **Linear coupling:** Dilaton $(\alpha = 1)$ **Damour, Vilenkin '97** ,
  Moduli $(\alpha \gtrsim 1)$ **ES '09; Berezinsky, ES, Vilenkin '10; ES, Lunardini '12**

$$\mathcal{L} \sim \frac{\alpha}{m_p} \mu \int d^2\sigma \sqrt{-\gamma}\, \varphi. \tag{5}$$

- Higgs condensate **Vachaspati '10** , Higgs condensate on dark strings **Hyde, Long, Vachaspati '13**

$$\mathcal{L} \sim \kappa\eta \int d^2\sigma \sqrt{-\gamma}\, \varphi. \tag{6}$$

Scalar Particle Radiation

- **Quadratic coupling:** Srednicki, Theisen '87 $\rightarrow$ Not significant!

$$\mathcal{L} \sim \lambda \int d^2\sigma \sqrt{-\gamma}\, \varphi^2. \tag{7}$$

- **Linear coupling:** Dilaton ($\alpha = 1$) Damour, Vilenkin '97 ,
  Moduli ($\alpha \gtrsim 1$) ES '09; Berezinsky, ES, Vilenkin '10; ES, Lunardini '12

$$\mathcal{L} \sim \frac{\alpha}{m_p} \mu \int d^2\sigma \sqrt{-\gamma}\, \varphi. \tag{8}$$

- Higgs condensate Vachaspati '10 , Higgs condensate on dark strings Hyde, Long, Vachaspati '13

$$\mathcal{L} \sim \kappa\eta \int d^2\sigma \sqrt{-\gamma}\, \varphi. \tag{9}$$

Tune in for JEFF HYDE'S and ANDREW LONG'S talks after lunch!

Scalar Particle Radiation

This talk $\rightarrow$ Scalar Fields with $\alpha \gtrsim 1$ **ES '09; Berezinsky, ES, Vilenkin '10; ES, Lunardini '12**

$$\mathcal{L} \sim \frac{\alpha}{m_p} \mu \int d^2\sigma \sqrt{-\gamma}\, \varphi. \tag{10}$$

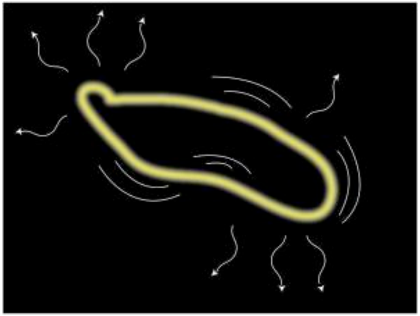
Radiation Power Spectrum

$$\frac{dP_n}{d\Omega} = \frac{G\alpha^2}{2\pi}\omega_n k|T(\mathbf{k},\omega_n)|^2, \qquad \omega_n = \sqrt{k^2+m^2} = 4\pi n/L. \tag{11}$$

$$T(\mathbf{k},\omega_n) = -\frac{4\mu}{L}\int d^4x \int d\sigma d\tau \sqrt{-\gamma}\delta^4[x^\alpha - X^\alpha(\sigma,\tau)]e^{ik_\nu X^\nu(\sigma,\tau)}. \tag{12}$$

Radiation Power Spectrum

$$\frac{dP_n}{d\Omega} = \frac{G\alpha^2}{2\pi}\omega_n k|T(\mathbf{k},\omega_n)|^2, \qquad \omega_n = \sqrt{k^2+m^2} = 4\pi n/L. \tag{13}$$



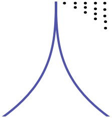
$$T(\mathbf{k},\omega_n) = -\frac{4\mu}{L}\int d^4x \int d\sigma d\tau \sqrt{-\gamma}\delta^4(x^\alpha - X^\alpha(\sigma,\tau))e^{ik_\nu X^\nu(\sigma,\tau)}. \tag{14}$$

Significant Radiation

- Small Loops $\rightarrow$ $P \sim \alpha^2 G\mu^2$ Exponentially suppressed unless $L \lesssim 1/m$, emitted at rest isotropically: $\Omega = 4\pi$. **Damour,Vilenkin '97; ES '09**

Significant Radiation

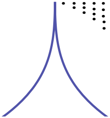
• Small Loops $\rightarrow P \sim \alpha^2 G\mu^2$ Exponentially suppressed unless $L \lesssim 1/m$, emitted at rest isotropically: $\Omega = 4\pi$. **Damour,Vilenkin '97; ES '09**



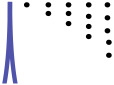
• Cusps $\rightarrow P \sim \alpha^2 G\mu^2/\sqrt{mL}$, Highly boosted particles $(E \sim m\sqrt{mL})$, emitted into a narrow cone: $\Omega \sim \pi/\gamma^2$. **Berezinsky, ES, Vilenkin '10; Vachaspati '10**

Significant Radiation

• Small Loops $\rightarrow$ $P \sim \alpha^2 G\mu^2$ Exponentially suppressed unless $L \lesssim 1/m$, emitted at rest isotropically: $\Omega = 4\pi$. **Damour,Vilenkin '97; ES '09**



• Cusps $\rightarrow$ $P \sim \alpha^2 G\mu^2$, Highly boosted particles ($E \sim m\sqrt{mL}$), emitted into a narrow cone: $\Omega \sim \pi/\gamma^2$. **ES '09; Berezinsky, ES, Vilenkin '10; Vachaspati '10**



• Kinks $\rightarrow$ $P \sim \alpha^2 G\mu^2 \log(m_s/m)$, Highly boosted particles ($E \sim m\sqrt{mL}$), emitted into into a narrow ribbon: $\Omega \sim 2\pi/\gamma$. **ES, Lunardini '12**

Cosmological Constraints on Moduli Radiation from Small Loops ($L \lesssim 1/m$)

• Abundance of moduli are constrained by diffuse gamma ray background, BBN, dark matter abundance. **Damour, Vilenkin '97; ES '09**

Cosmological Constraints on Moduli Radiation from Small Loops ($L \lesssim 1/m$)

- Abundance of moduli are constrained by diffuse gamma ray background, BBN, dark matter abundance. **Damour, Vilenkin '97; ES '09**

- Gravitationally coupled scalar fields ($\alpha = 1$) are constrained significantly. **Damour, Vilenkin '97**

Cosmological Constraints on Moduli Radiation from Small Loops ($L \lesssim 1/m$)

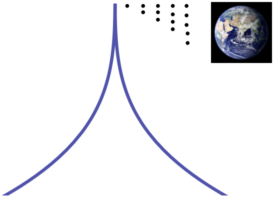
• Abundance of moduli are constrained by diffuse gamma ray background, BBN, dark matter abundance. **ES '09**

• Gravitationally coupled scalar fields ($\alpha = 1$) are constrained significantly. **Damour, Vilenkin '97**

• Scalar fields with stronger coupling ($\alpha > 1$) are less constrained because loops disappear more quickly! **ES '09**

Ultra High Energy Neutrinos from Cusps and Kinks

- Scalar particles are emitted from cusps and kinks with Lorentz factors of $\gamma_c \sim \sqrt{mL} >> 1$ into a narrow opening angle $\theta_c \sim 1/\gamma_c$.



- The rate of particle bursts that occur at redshift z in the interval $(z, z + dz)$:

$$d\dot{N}_b = \frac{n(L,z)\, dL}{L/2} \frac{\Omega}{4\pi} \frac{dV(z)}{1+z}. \quad (15)$$

- The diffuse flux of neutrinos from bursts originating at redshifts $\sim z$:

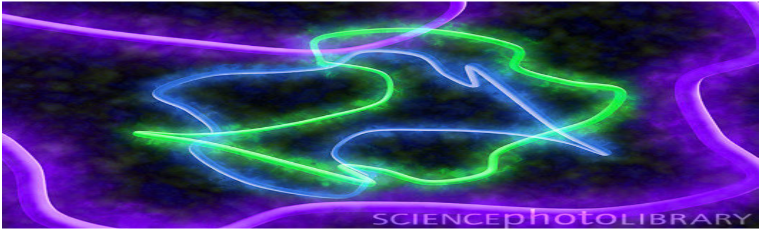
$$J_\nu(E;z) = \frac{(1+z)}{4\pi} \int \frac{d\dot{N}_b}{dz}\, \xi_\nu(E,k) \frac{dN(k)}{\Omega_k r^2(z)}. \quad (16)$$

Particle Radiation from Superconducting String Cusps

• Superheavy charge carriers are ejected from parts of strings, where the current is saturated: Easily achieved at cusps. **Berezinsky, Olum, ES, Vilenkin '09.**

$$\frac{dN_X}{dt} \sim 2I^2/e\, I_{max}, \tag{17}$$

$$I \lesssim I_{max} \sim i_c e\eta, \quad i_c \lesssim 1. \tag{18}$$

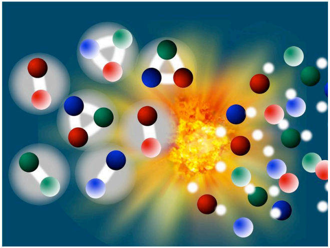


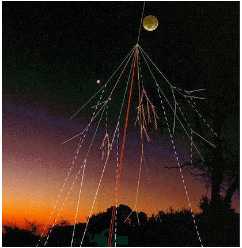
• String tension: $G\mu \sim \eta^2/m_p^2$.

• Mass of the charge carrier: $m_X \sim i_c\eta$.

Fragmentation Function for Neutrinos

- The neutrinos are produced via pions produced from hadronic cascades.





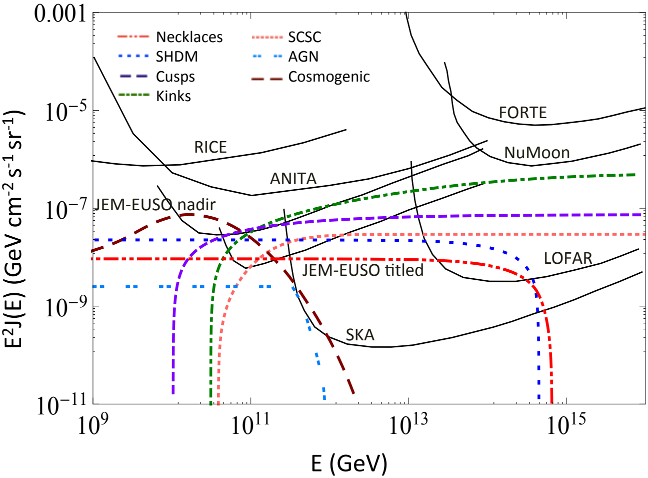
- The fragmentation function: $dN/dE \propto E^{-2}$

Berezinsky, Kachelriess '01.

- The minimum neutrino energy: $E_{min} \sim (1\,\mathrm{GeV})\gamma/(1+z)$.

UHE Neutrino Fluxes, Detectability Limits, Upper Bounds

Figure from **Lunardini, ES, Yang '13**



Cosmic Necklaces:**Berezinsky, Martin, Vilenkin '97**; Super Heavy Dark Matter (SHDM):**Berezinsky, Kachelriess, Vilenkin '98; Kuzmin, Rubakov '98**: Cosmic String Cusps:**Berezinksy, ES, Vilenkin '11**; Cosmic String Kinks:**Lunardini, ES '12**; Superconducting Cosmic Strings:**Berezinsky, ES, Olum, Vilenkin '09**; Active Galactic Nuclei:**Kalashev, Kuzmin, Semikoz, Sigl '02**: Cosmogenic Neutrinos:**Berezinsky, Zatsepin '69; Engel, Seckel, Stanev '01**.