Cosmic strings

Håkon Enger

Overview

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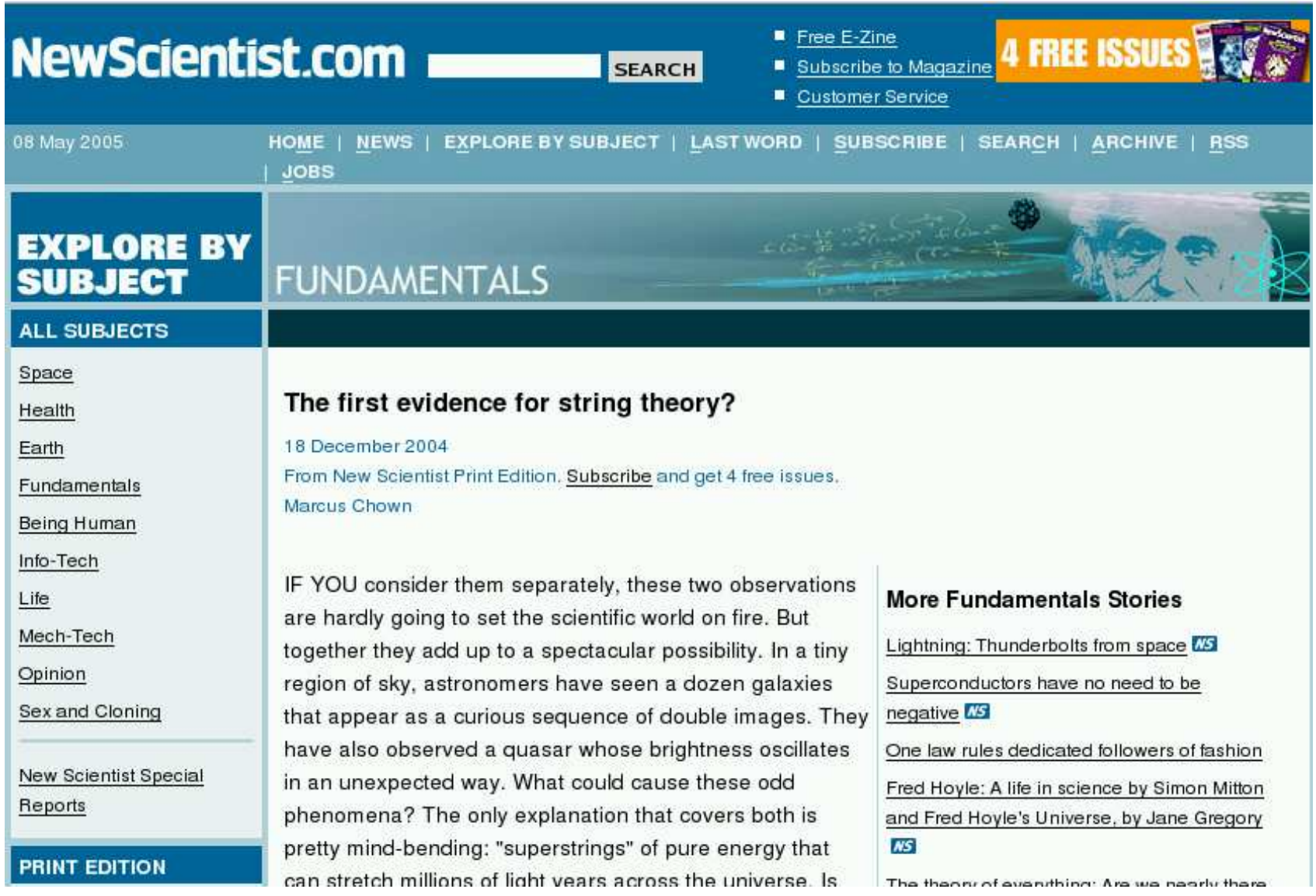
- Cosmic strings and CMB
- Cosmic superstrings
- Observations

String theory proven?



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PRINT EDITION

The first evidence for string theory?

18 December 2004

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Marcus Chown

IF YOU consider them separately, these two observations are hardly going to set the scientific world on fire. But together they add up to a spectacular possibility. In a tiny region of sky, astronomers have seen a dozen galaxies that appear as a curious sequence of double images. They have also observed a quasar whose brightness oscillates in an unexpected way. What could cause these odd phenomena? The only explanation that covers both is pretty mind-bending: "superstrings" of pure energy that can stretch millions of light years across the universe. Is

More Fundamentals Stories

Lightning: Thunderbolts from space NS

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One law rules dedicated followers of fashion

Fred Hoyle: A life in science by Simon Mitton and Fred Hoyle's Universe, by Jane Gregory NS

The theory of everything: Are we nearly there

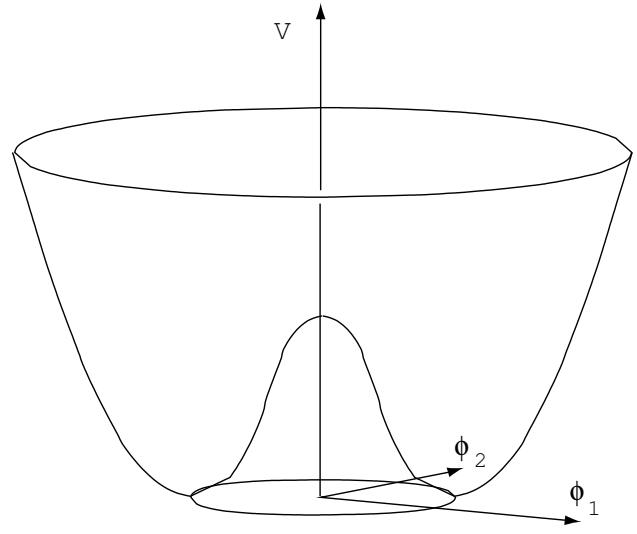
Spontaneous symmetry breaking

- Complex scalar ϕ
- Potential

$$V \sim (|\phi|^2 - \eta^2)^2$$

(η const)

- Symmetry breaking: ground state not rotationally symmetric



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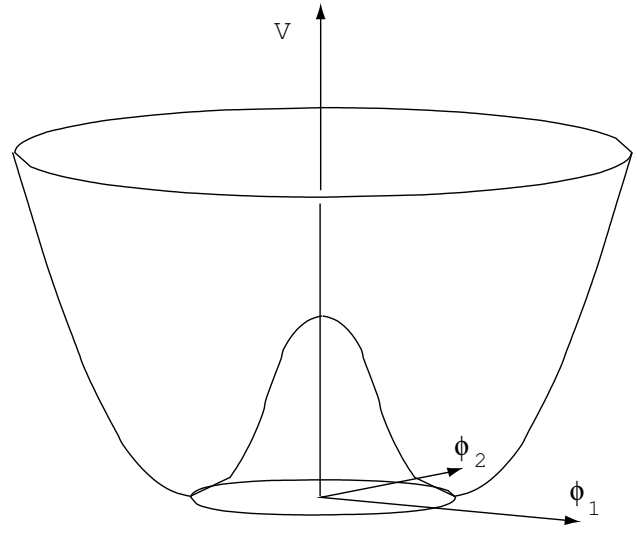
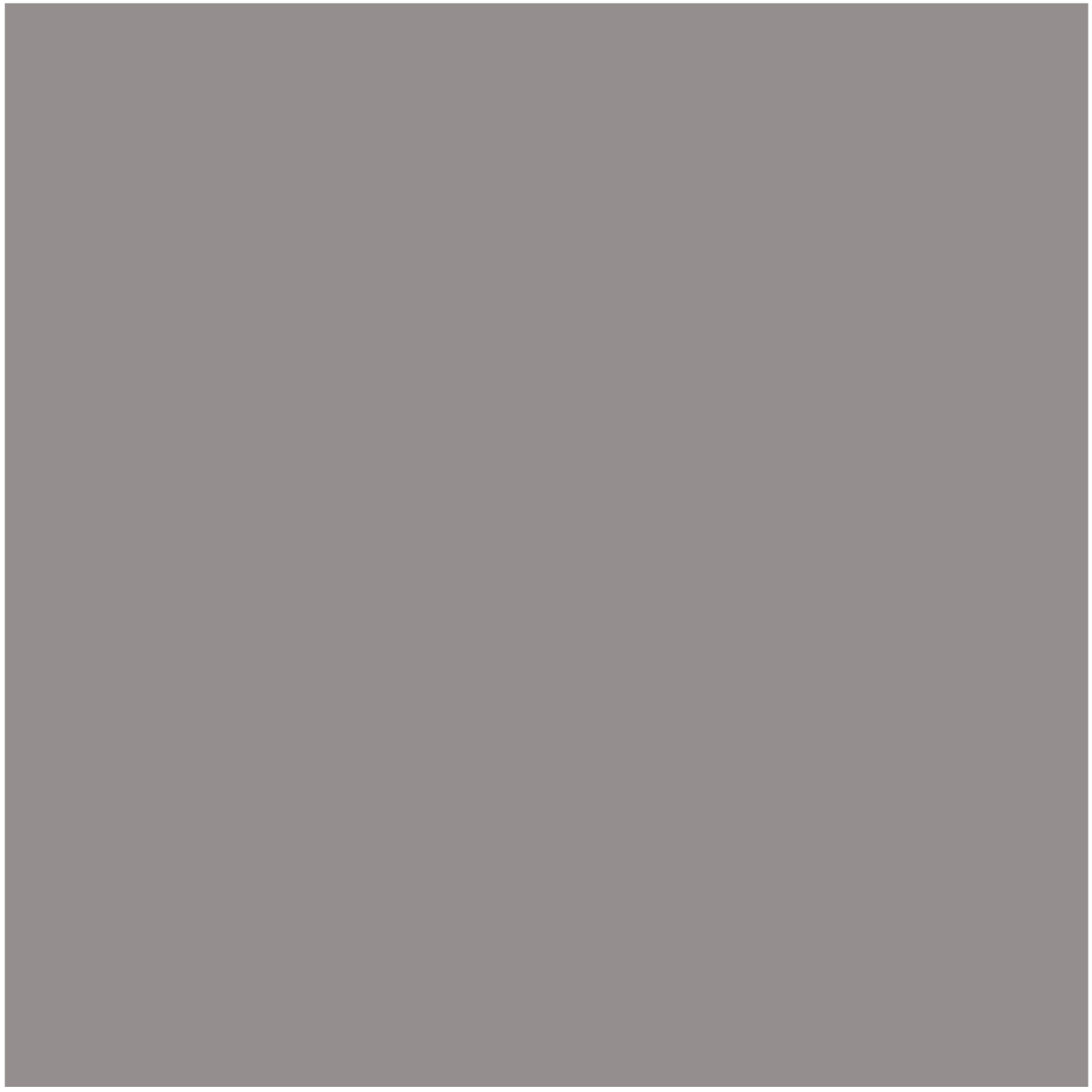
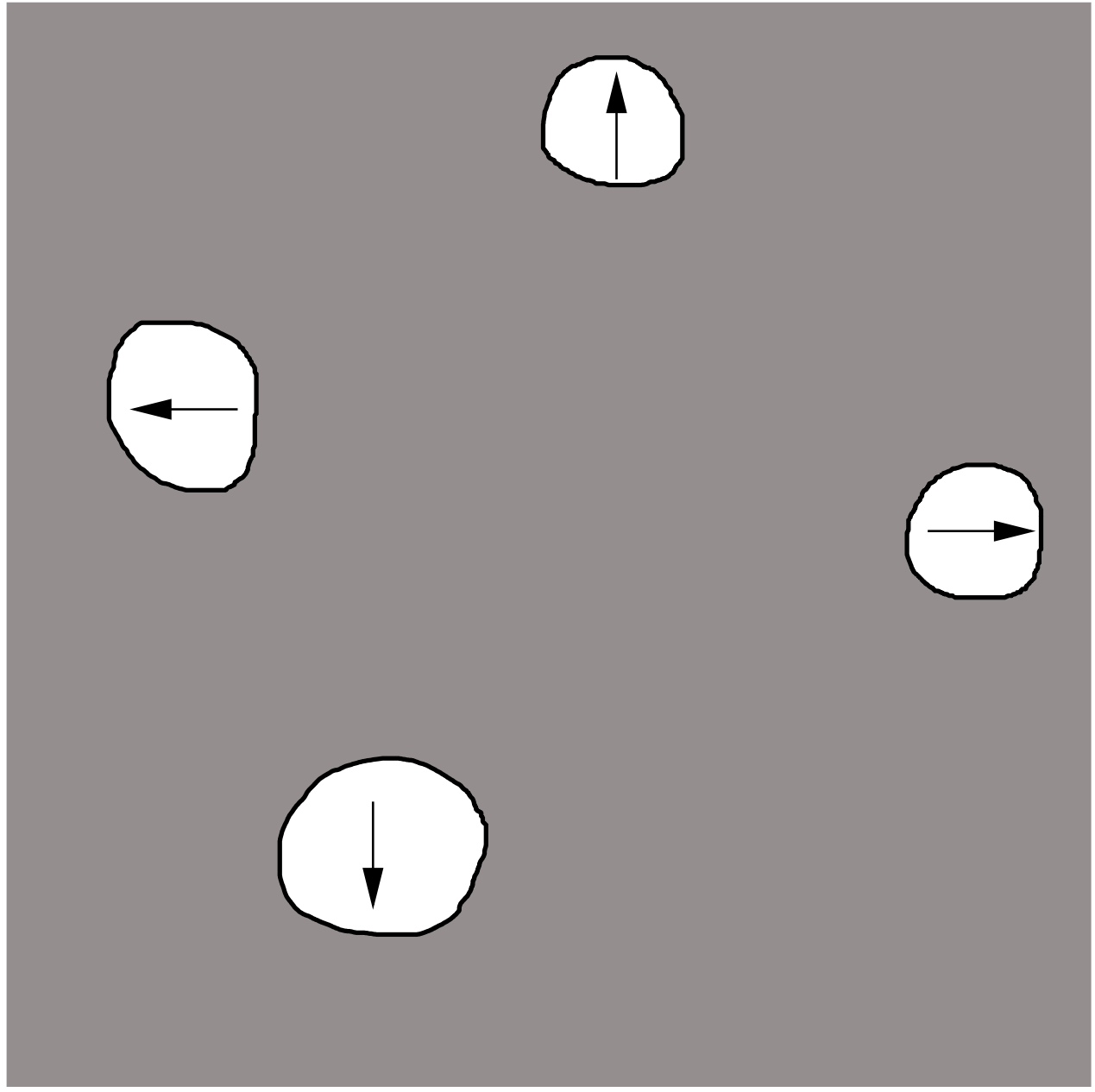


- Symmetry breaking: ground state not rotationally symmetric
- Effective potential temperature dependent
- High T: Symmetric ground state $\phi = 0$
- Symmetry breaking at critical T

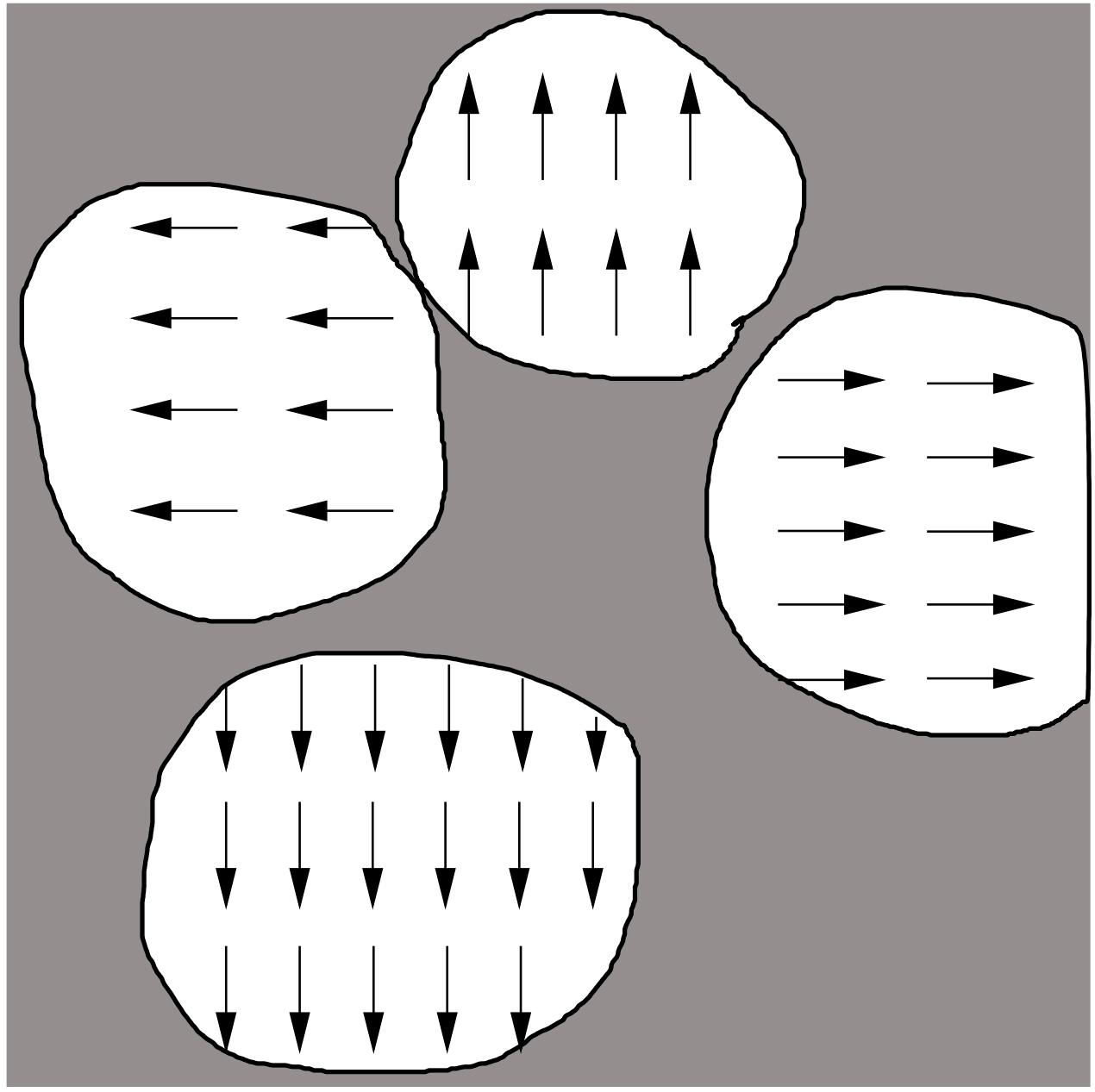
Early Universe



Early Universe



Early Universe



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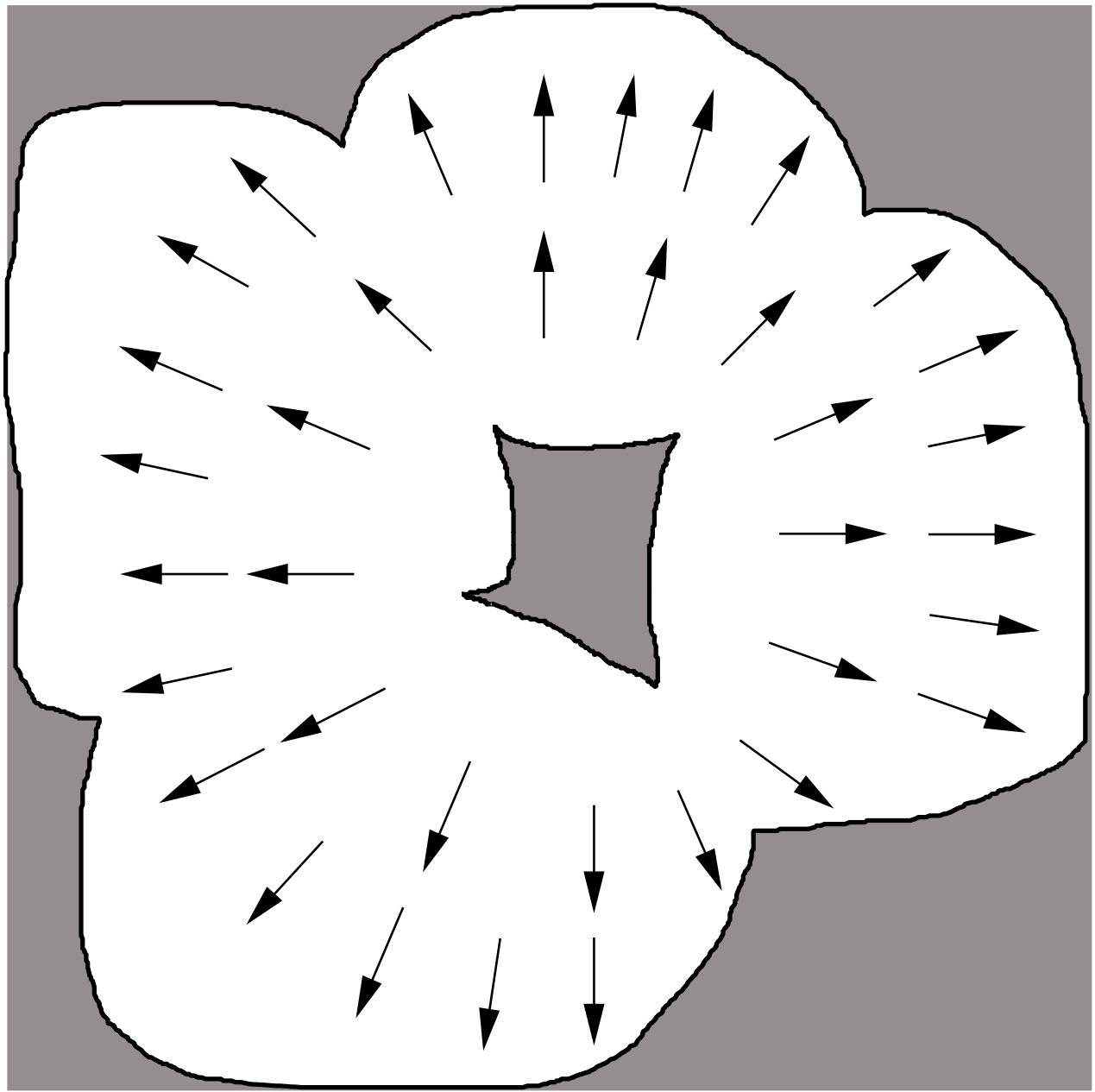

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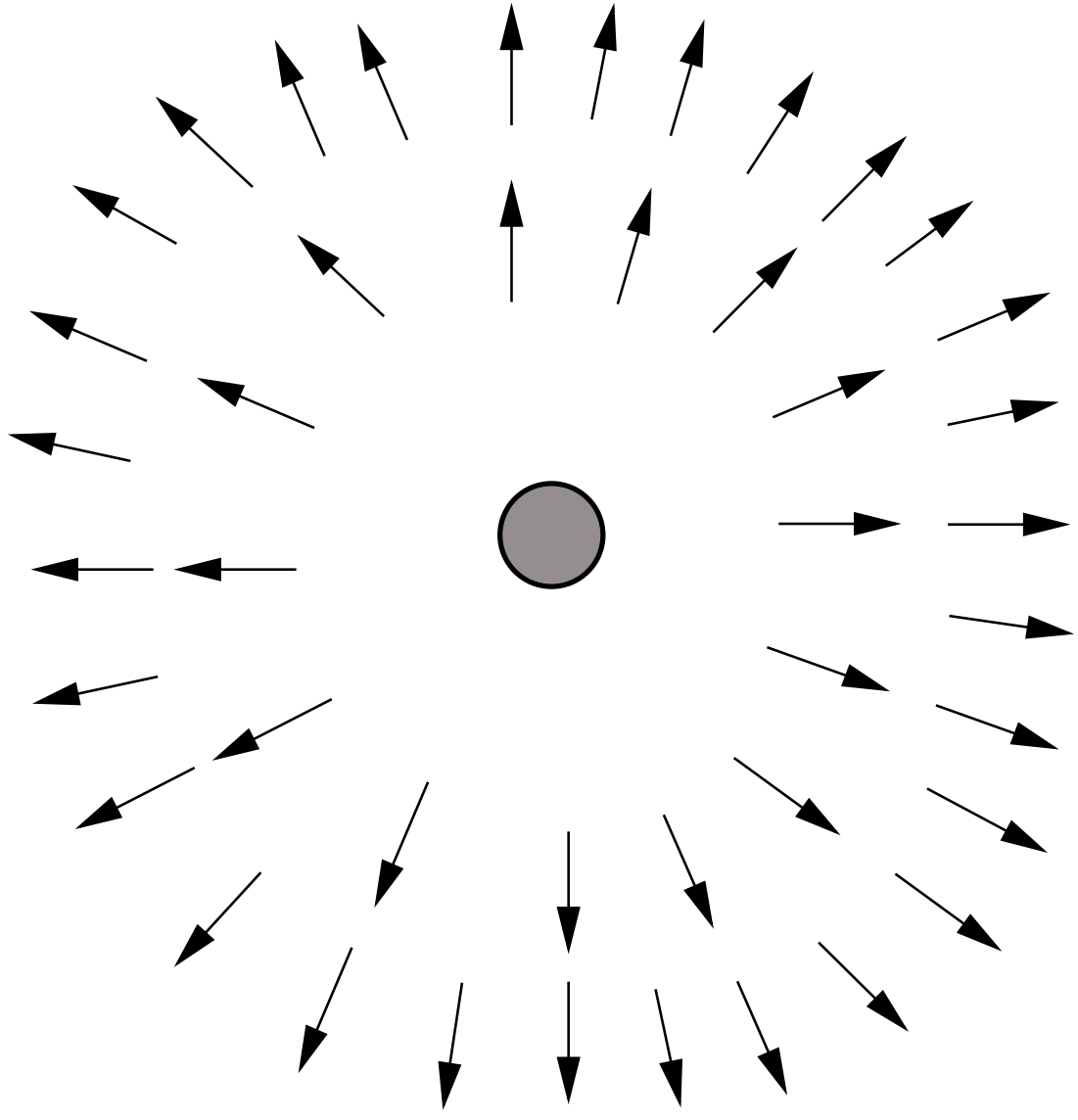

Symmetry breaking in gauge theories

- Higgs mechanism:

$$SU(2) \times U(1) \longrightarrow U(1)$$

- Energy: $\sim 100\,\mathrm{GeV}$.

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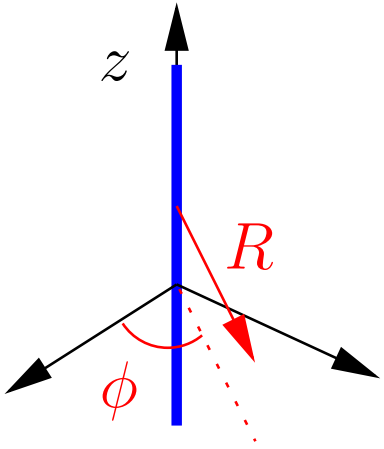
- "Theory of everything" at Planck scale?
- Energy: $\sim 10^{19}\,\mathrm{GeV}$.

Gravitational field of a string

- Long straight string
- Simplest strings are *Lorentz invariant* along string.



Energy-momentum tensor in this case:

$$T^{tt} = \mu\delta^2(R) \qquad T^{zz} = -\mu\delta^2(R)$$

Solution of Einstein's equations $\rightsquigarrow$

$$ds^2 = dt^2 - dz^2 - dR^2 - (1 - 4G\mu)^2 R^2 d\phi^2$$

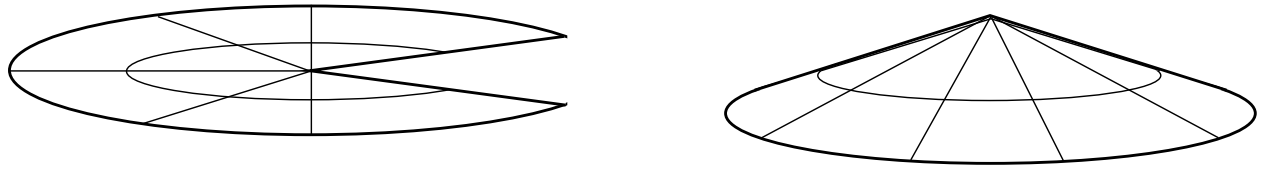
Gravitational field of a string

$$ds^2 = dt^2 - dz^2 - dR^2 - (1 - 4G\mu)^2 R^2 d\phi^2$$

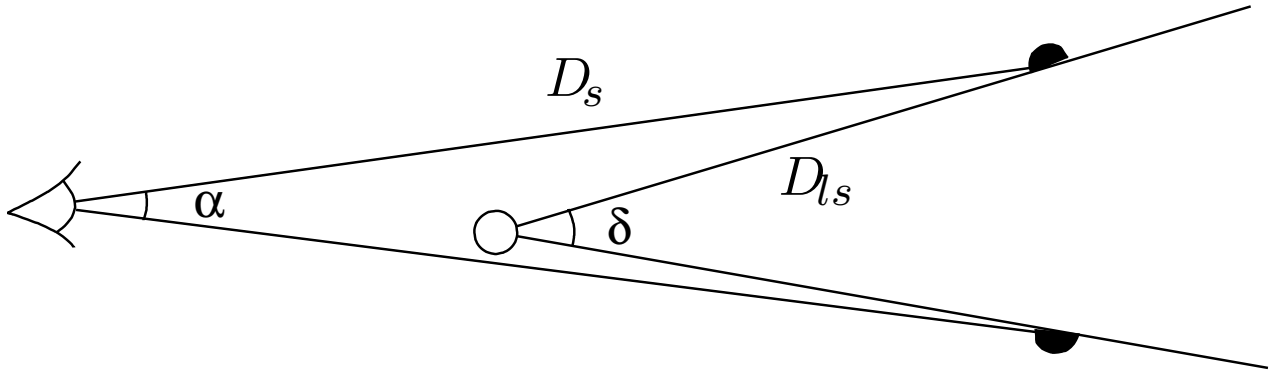
The coordinate transform $\phi' = (1 - 4G\mu)\phi$ gives flat space.

But: now $0 \leq \phi' < 2\pi - 8\pi G\mu$

Conical singularity at $R = 0$.



Lensing effect of string



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- Can compute α from D_s and D_{ls}.

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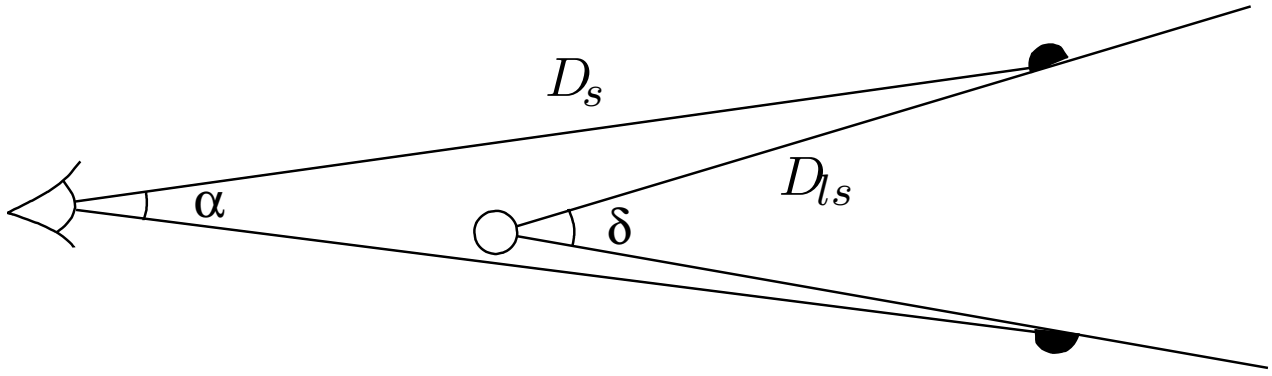

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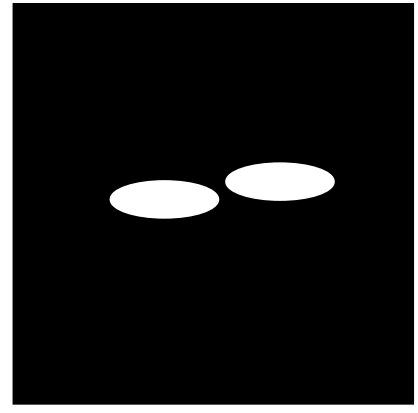
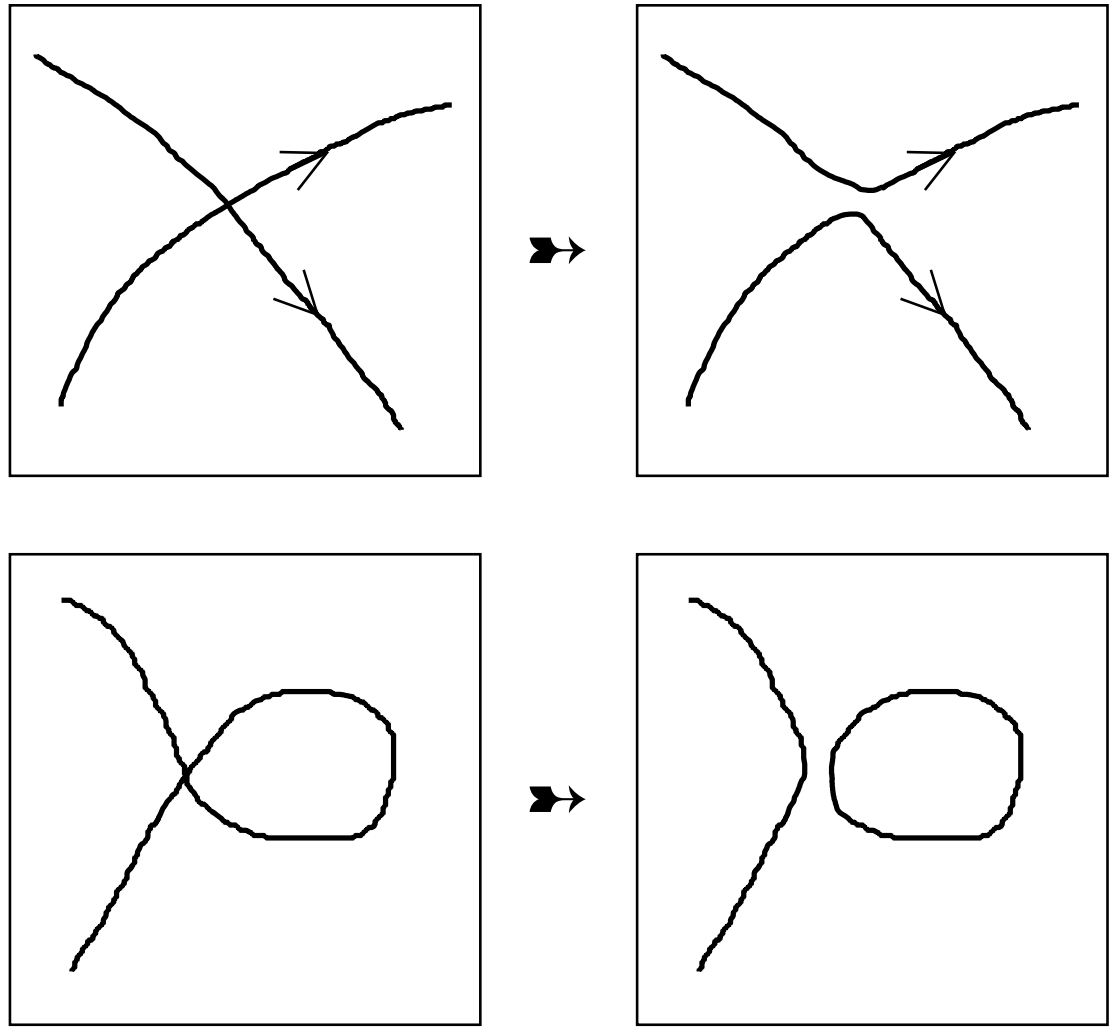
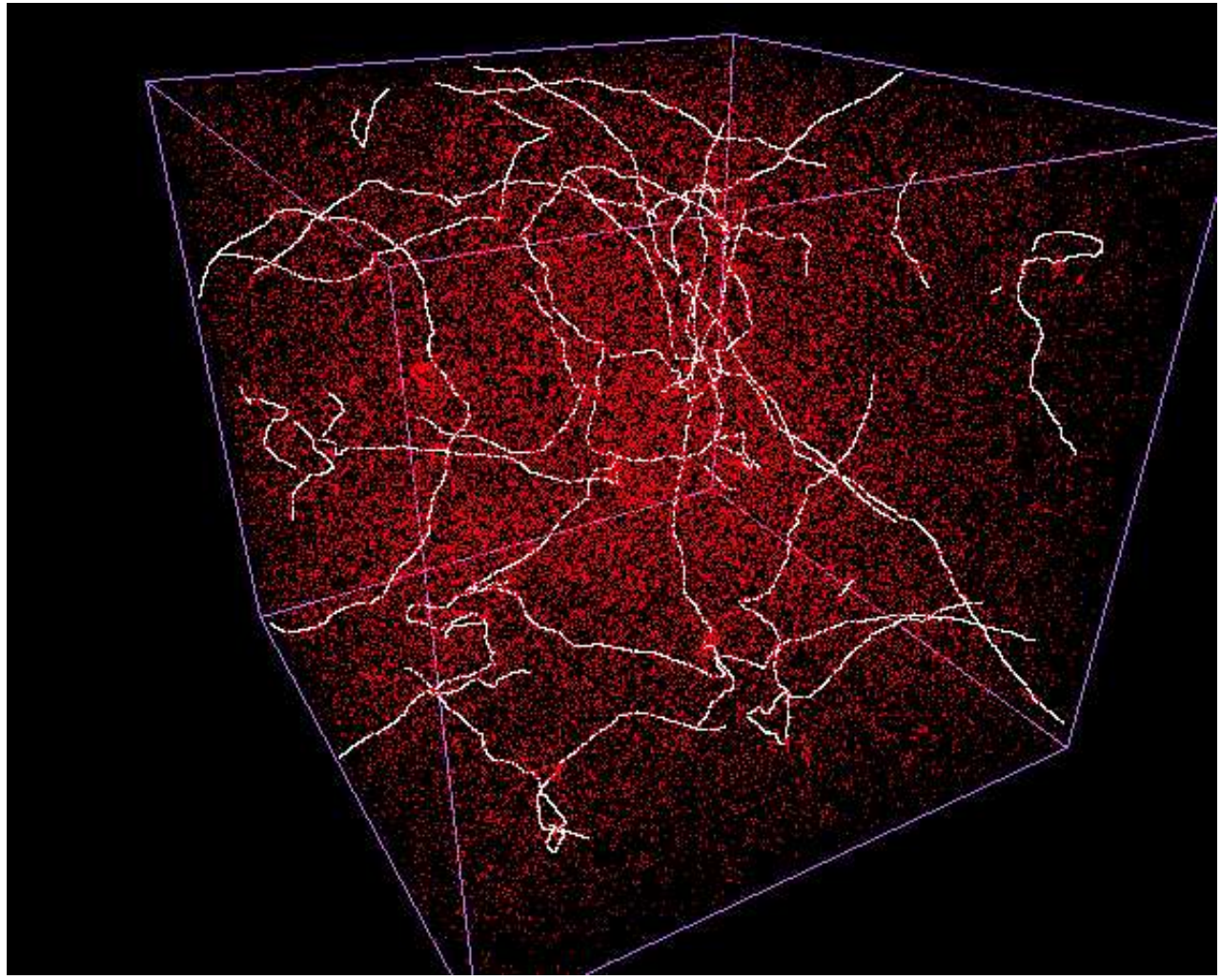


Development of cosmic strings



Network of cosmic strings



[theory.physics.unige.ch/∼ringeval/strings.html]

Strings and mass distribution

- Problem: How were the galaxies formed?
- Need fluctuations of mass density to start galaxy formation.

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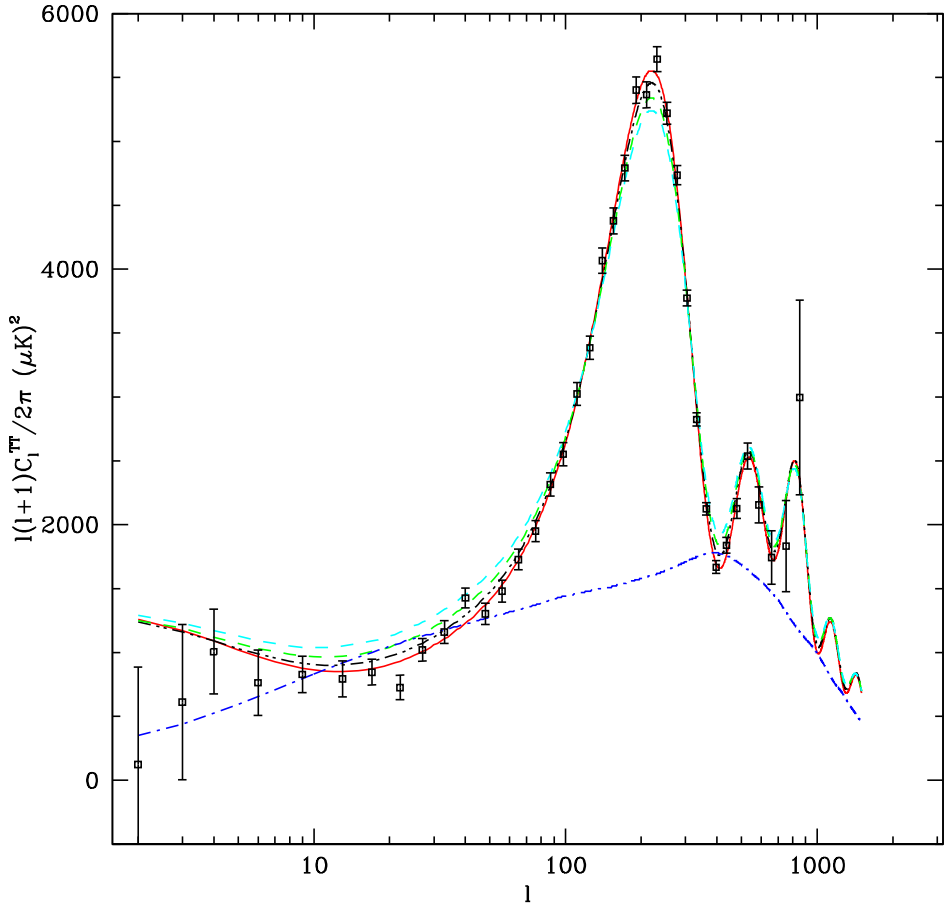
- Alternative: inflation...

Cosmic strings and CMB

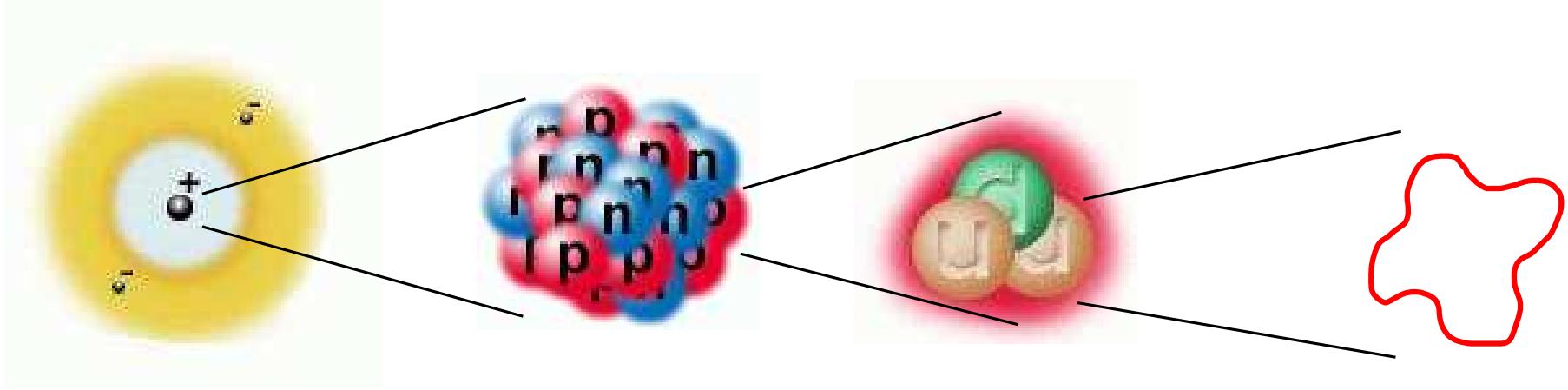


The WMAP satellite has measured the fluctuations in the cosmic microwave background radiation (CMB). Looks bad for strings…

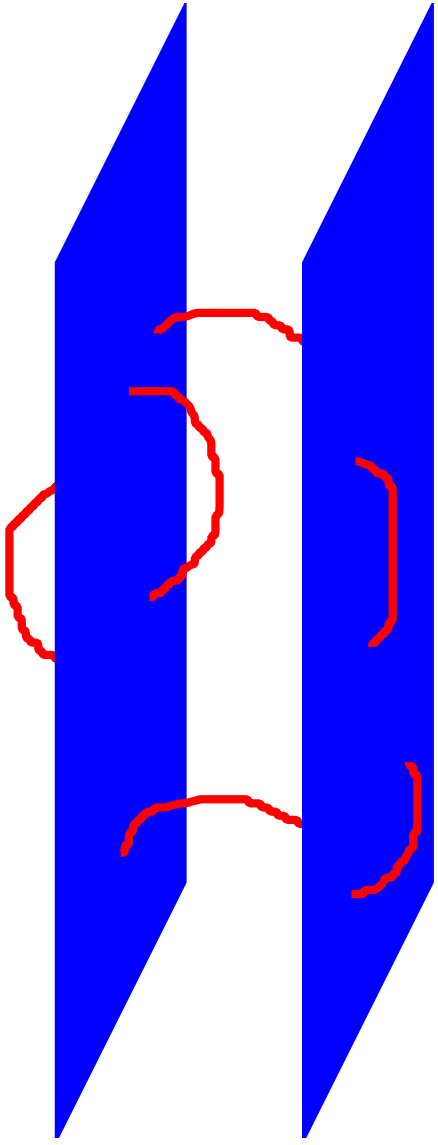
[hep-th/0505050]

String theory

- Fundamental objects are strings, not points
- Supersymmetry
- Extra dimensions
- Fundamental strings: $\mu = 1 \,/\, 2\pi\alpha' \sim 10^{19}\mathrm{GeV}$

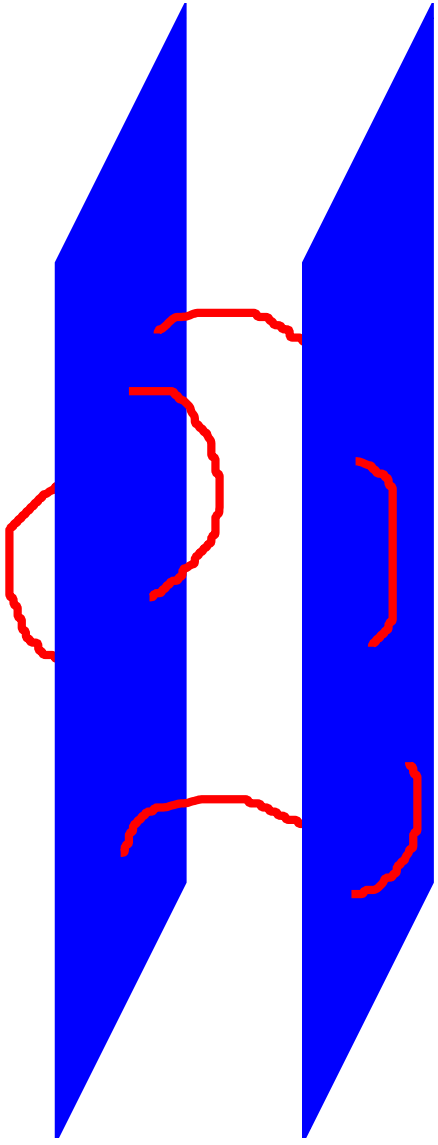


D-branes



- Extended objects
- Connects to open strings
- May have any number of dimensions

D-branes



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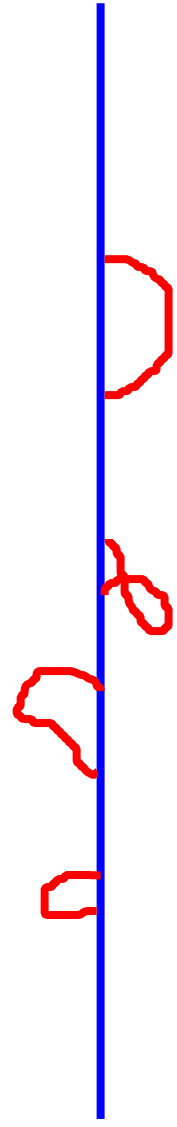
- Connects to open strings
- May have any number of dimensions
- E.g: D1-brane
  = D-string



Brane-world models

- Our universe is a D3 brane
- "Large" extra dimensions: $\mu \mapsto \mu/V$
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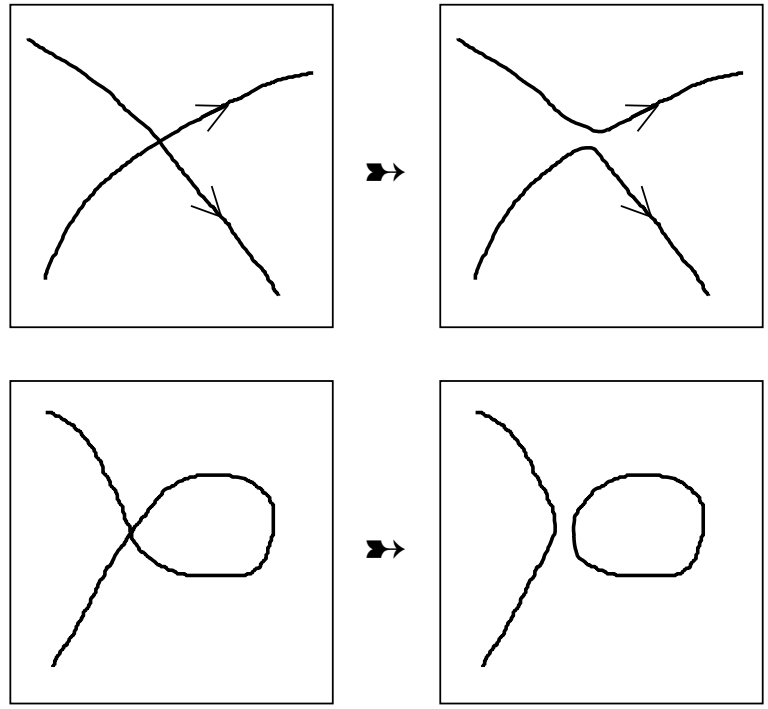
Inflation:

- $\mathbb{KLMT}$ model
- $\mathrm{D3}/\overline{\mathrm{D3}}$ pairs collide
- Annihilation produces D-strings

Signatures of superstrings

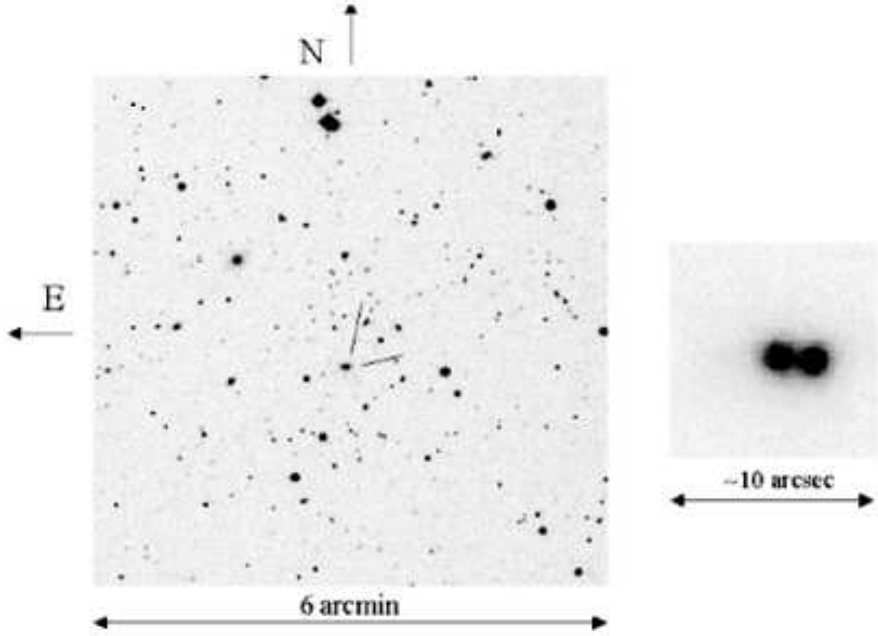
- F- and D-strings do not necessarily reconnect at collisions
- Probability $0 < P < 1$ depends e.g. on string coupling g_s
- Small P gives more large strings

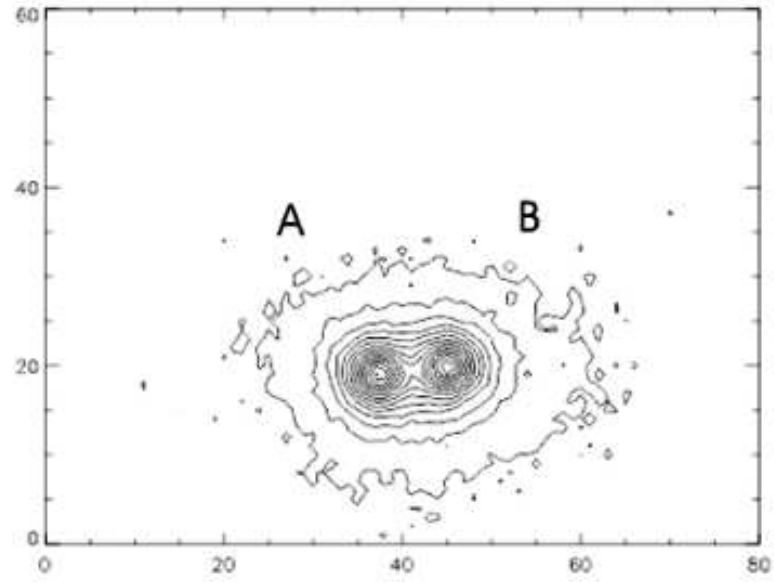


Observations

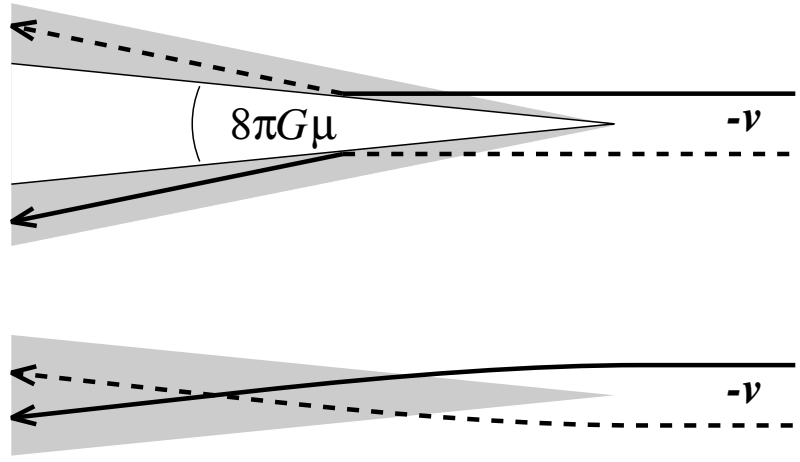
CSL-1

- "CSL-1: a chance projection effect or serendipitous discovery of a gravitational lens induced by a cosmic string?"
- M. Sazhin et. al., Mon. Not. Roy. Astron. Soc. **343** (2003) 353 [astro-ph/0302547]





Edges in CMB



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- A. S. Lo, E. L. Wright, [astro-ph/0503120], looked for edges in WMAP data
- No clear evidence of strings

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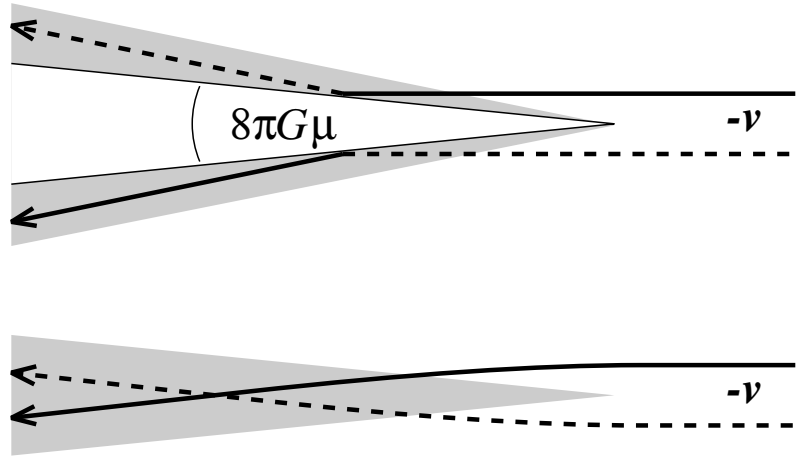

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- No clear evidence of strings
- Edge at CSL-1 with “2σ” significance

The double quasar

Anomalous fluctuations in observations of Q0957+561 A,B: smoking gun of a cosmic string?

R. Schild[1], I. S. Masnyak[2], B. I. Hnatyk[2], and V. I. Zhdanov[2]

[1] Harvard-Smithsonian Center for Astrophysics, 19, 60 Garden Street, Cambridge, MA 02138, U.S.A.
[2] Astronomical Observatory of Kyiv Taras Shevchenko National University, 3 Observatorna str., 04053 Kyiv, Ukraine

the date of receipt and acceptance should be inserted later

Abstract. We report the detection of anomalous brightness fluctuations in the multiple image Q0957 + 561 A,B gravitational lens system, and consider whether such anomalies have a plausible interpretation within the framework of cosmic string theory. We study a simple model of gravitational lensing by an asymmetric rotating string. An explicit form of the lens equation is obtained and approximate relations for magnification are derived. We show that such a model with typical parameters of the GUT string can quantitatively reproduce the observed pattern of brightness fluctuations. On the other hand explanation involving a binary star system as an alternative cause requires an unacceptably large massive object at a small distance. We also discuss possible observational manifestations of cosmic strings within our lens model.

Key words. cosmology: miscellaneous – gravitational lensing – quasars: individual: Q0957+561 – dark matter – elementary particles

511 keV photons

- The INTEGRAL satellite has observed radiation of photons with 511 keV from the centre of the galaxy
- presumed source: electron-positron annihilation
- F. Ferrer, T. Vachaspati, [astro-ph/0505063]:
- Superconducting cosmic strings may produce positrons

Conclusion

- Cosmic strings: Produced by spontaneous symmetry breaking
- Small effect on mass distribution
- May be observed by gravitational lensing
- F- and D-strings from string theory
- So far no definitive observations

References:

Reviews:
Davis, Kibble: hep-th/0505050
Polchinski: hep-th/0412244
Hindmarsh, Kibble: Rep. Prog. Phys **58** (1995), 477

CSL-1: astro-ph/0302547
WMAP edges: astro-ph/0503120
Double quasar: astro-ph/0406434
511 keV photons: astro-ph/0505063