Strings

Håkon Enger

Large and small strings

- Small light strings: F-strings

Large and small strings

- Small light strings: F-strings
- Small heavy strings: D-strings

Large and small strings

- Small light strings: F-strings
- Small heavy strings: D-strings
- Big heavy strings: Cosmic strings

Small light strings

The foundation of (super)string theory:

- Elementary particles are strings, not points

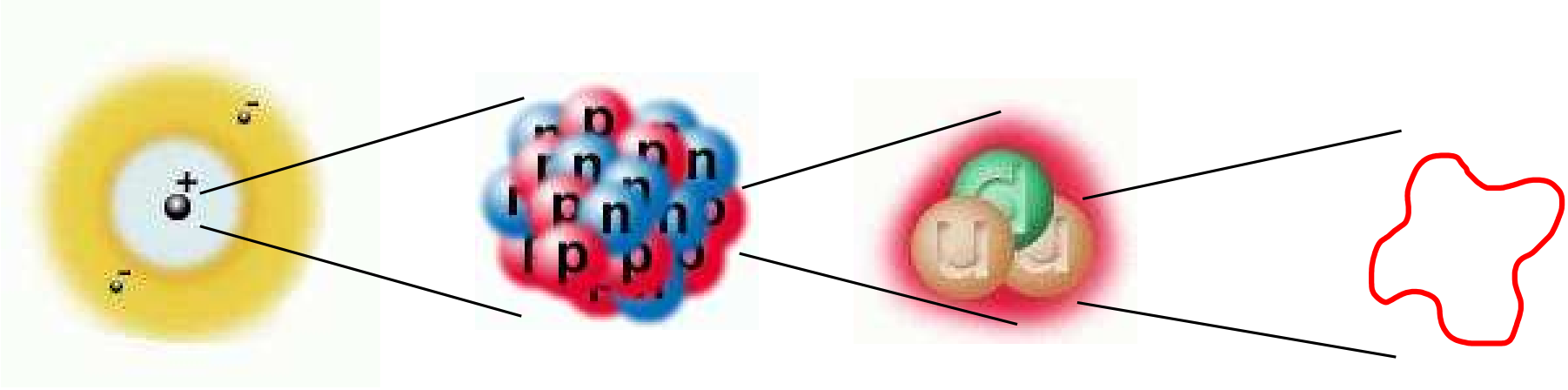
What is an elementary particle?

Small light strings

The foundation of (super)string theory:

- Elementary particles are strings, not points

What is an elementary particle?



(Sometimes called F(undamental)-string)

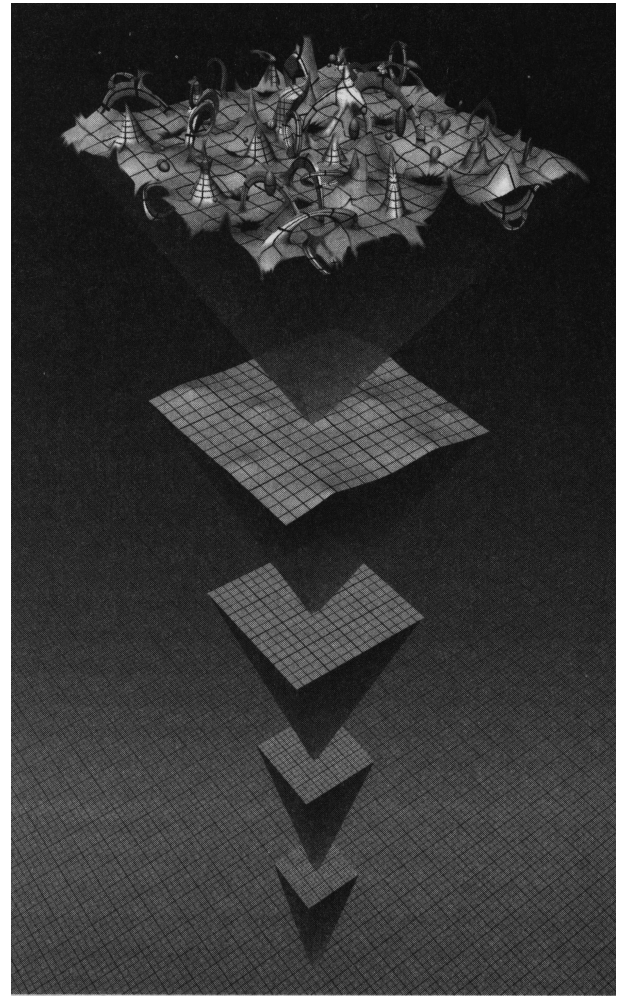
Why?

Why?

- Why not?
  - We can’t observe elementary particles in enough detail to see what shape they have. . .

Why?

- Mathematical problems with quantum physics:
  - Gravtity not consistent with renormalization
  - Thus, there is no theory describing all four fundamental forces of nature

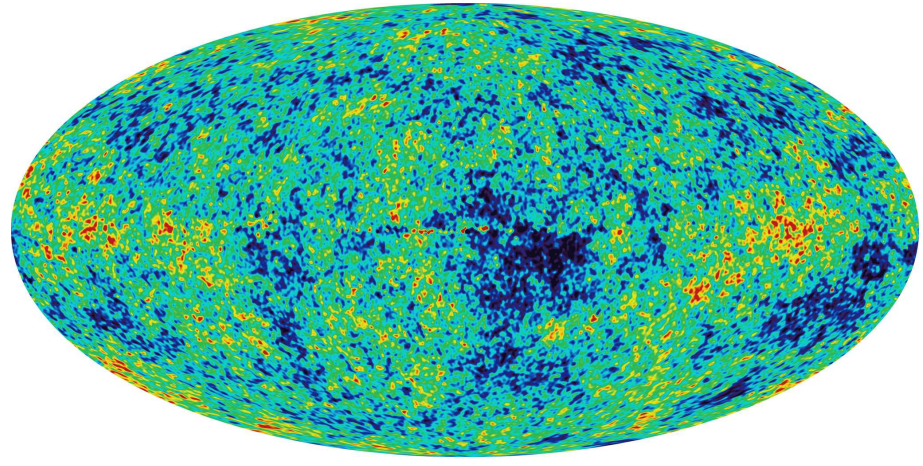


Why?

- Observational problems:
  - Galaxies seem to rotate too fast

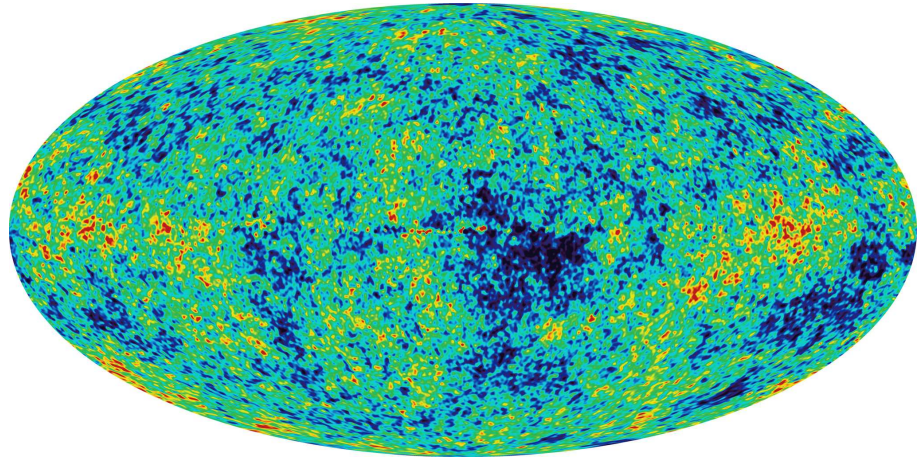
Why?

- Observational problems:
  - Galaxies seem to rotate too fast
  - Observation of the CMB suggests a mysterious vacuum energy filling empty space



Why?

- Observational problems:
  - Galaxies seem to rotate too fast
  - Observation of the CMB suggests a mysterious vacuum energy filling empty space
  - Normally solved by introducing “dark matter/energy”, but what is it?



String theory

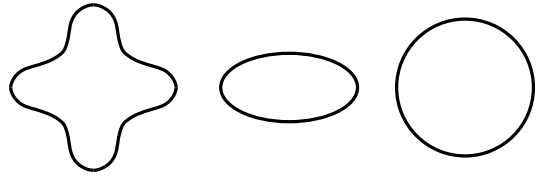
- Two kinds of strings: open and closed

Open strings give ut the Standard Model of particle physics (matter + electromagnetic + nuclear forces)

String theory

- Two kinds of strings: open and closed

Open strings give ut the Standard Model of particle physics (matter + electromagnetic + nuclear forces)

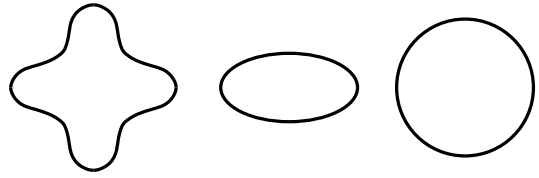


Closed strings are *gravitons* – carriers of gravitation.

String theory

- Two kinds of strings: open and closed

Open strings give ut the Standard Model of particle physics (matter + electromagnetic + nuclear forces)



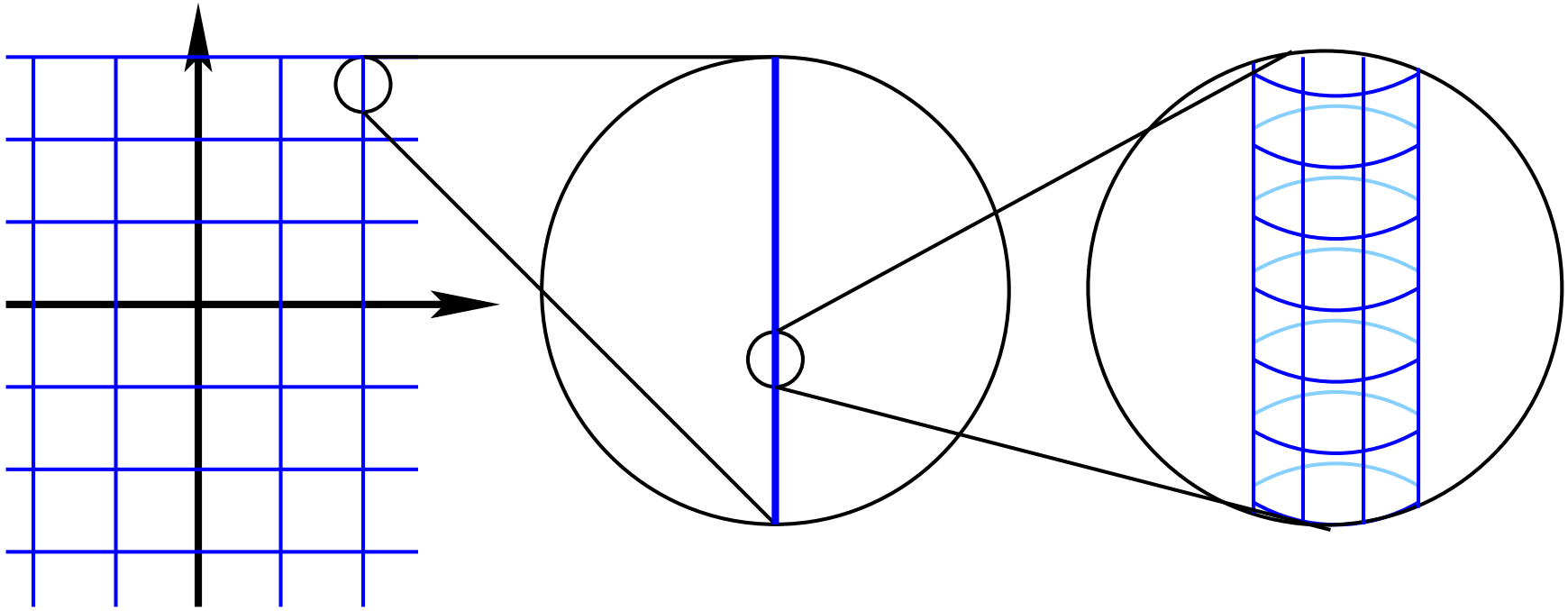
Closed strings are *gravitons* – carriers of gravitation. String theory contains *both* gravity and Standard Model forces – it's the (so far) only

Theory of everything!

Extra dimensions

Quantum field theory and supersymmetry restricts the theory mathematically

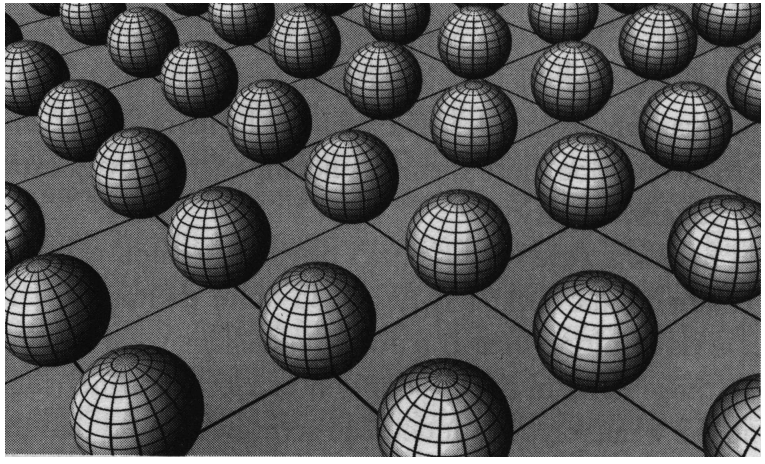
Space must have exactly 9 dimensions!

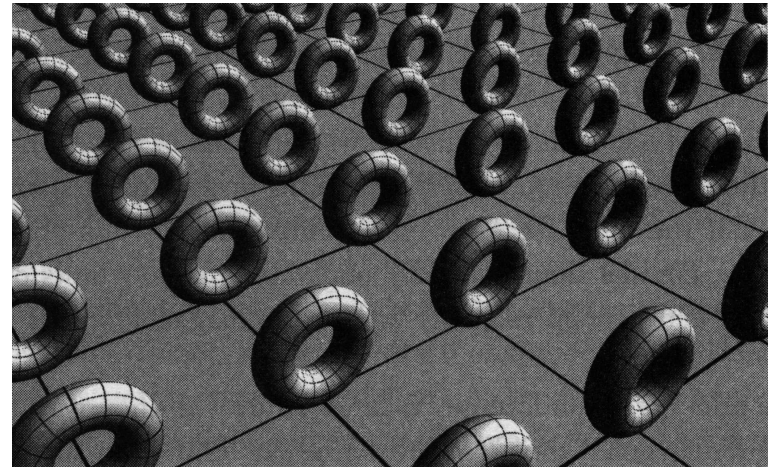


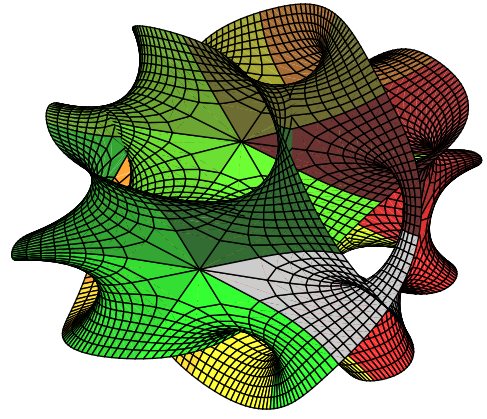
(Including time, we get $9+1=10$ dimensions all together.)

Extra dimensions

The extra dimensions are “curled up”, possibly in a very complicated way.

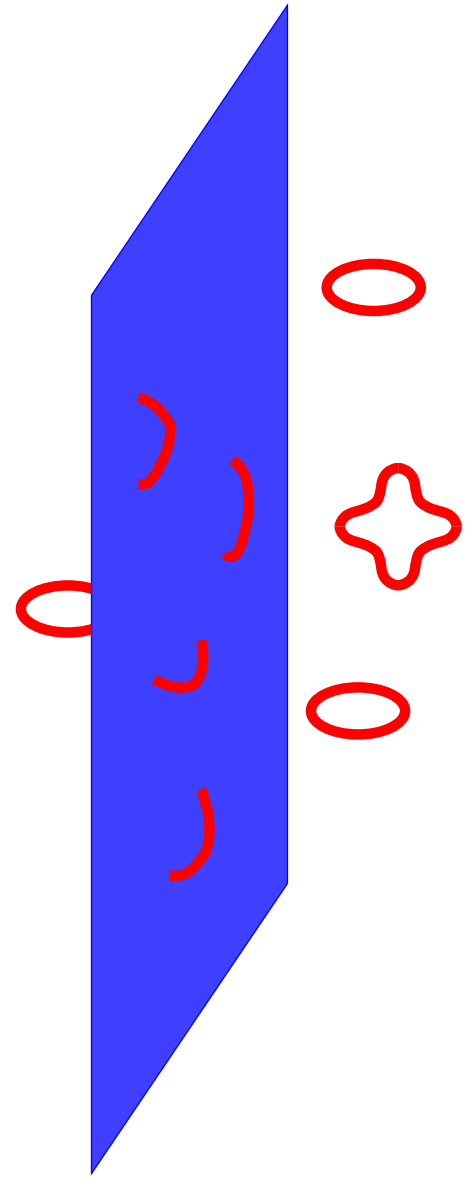






D-branes and D-strings

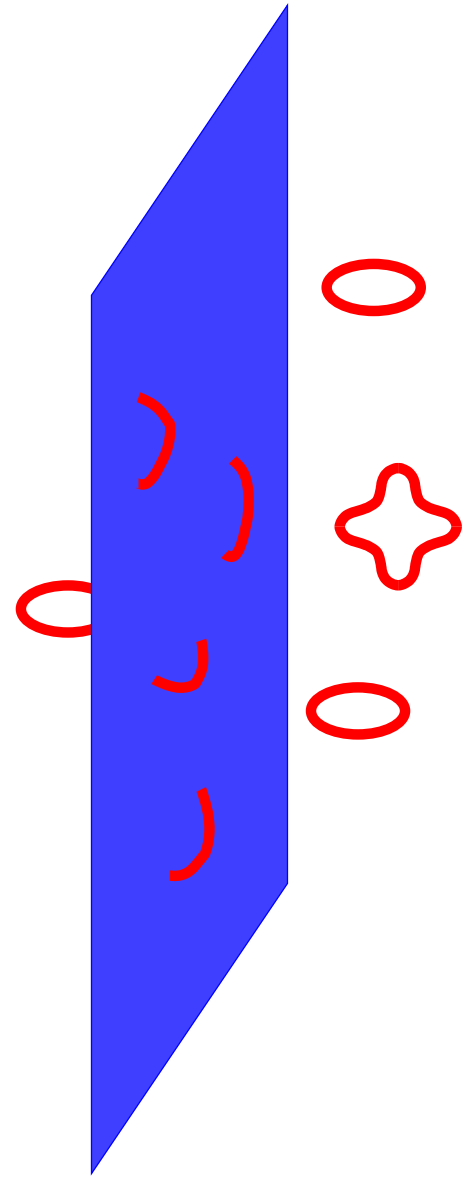
- “Discovered” (i.e., mathematically) in the 90s
- Massive objects extended in one or more dimensions



D-branes and D-strings

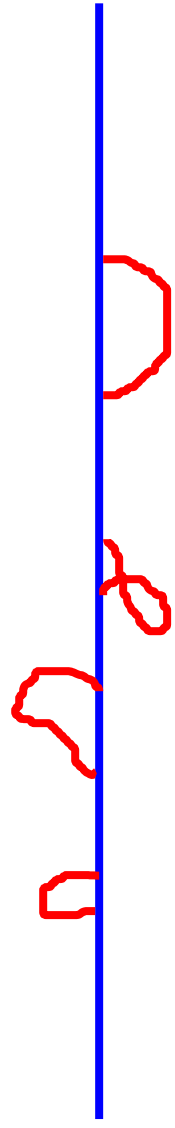
- "Discovered" (i.e., mathematically) in the 90s
- Massive objects extended in one or more dimensions
- *Open* strings attach to D-branes.
- *Closed* strings move in all 9 dimensions.

D-branes are essential to understanting non-perturbative aspects of string theory.

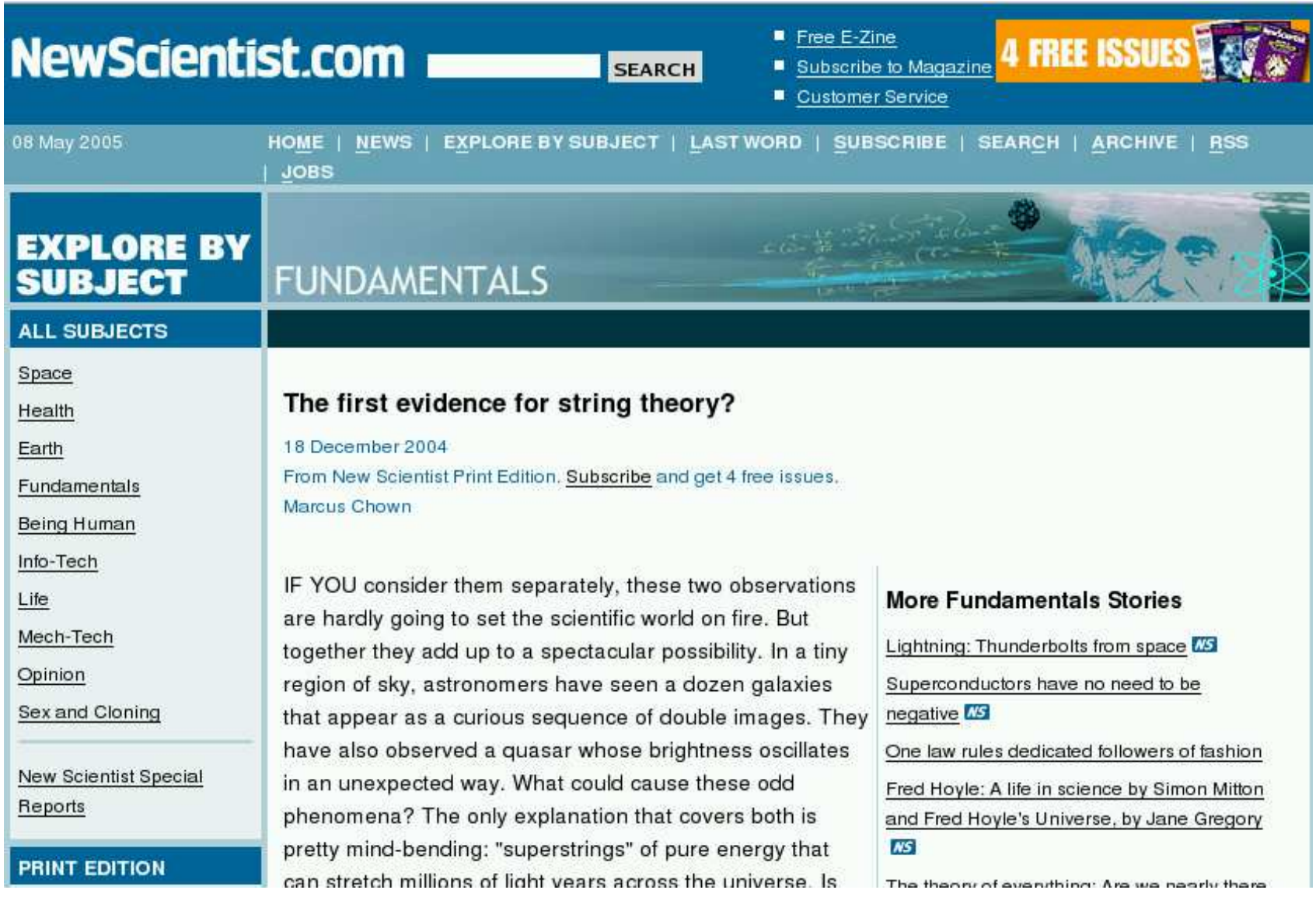


D-branes and D-strings

- A one-dimensional D-brane is called a D-string.
- A D-string is heavier than a F-string.
- Probably the D-strings (and branes) will be curled up in the extra dimensions, and look like (heavy) particles to us.



String theory proven?



NewScientist.com SEARCH

Free E-Zine
Subscribe to Magazine
Customer Service

4 FREE ISSUES

08 May 2005

HOME | NEWS | EXPLORE BY SUBJECT | LAST WORD | SUBSCRIBE | SEARCH | ARCHIVE | RSS | JOBS

EXPLORE BY SUBJECT

FUNDAMENTALS

ALL SUBJECTS

Space
Health
Earth
Fundamentals
Being Human
Info-Tech
Life
Mech-Tech
Opinion
Sex and Cloning

New Scientist Special Reports

PRINT EDITION

The first evidence for string theory?

18 December 2004
From New Scientist Print Edition. Subscribe and get 4 free issues.
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
Superconductors have no need to be negative NS
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

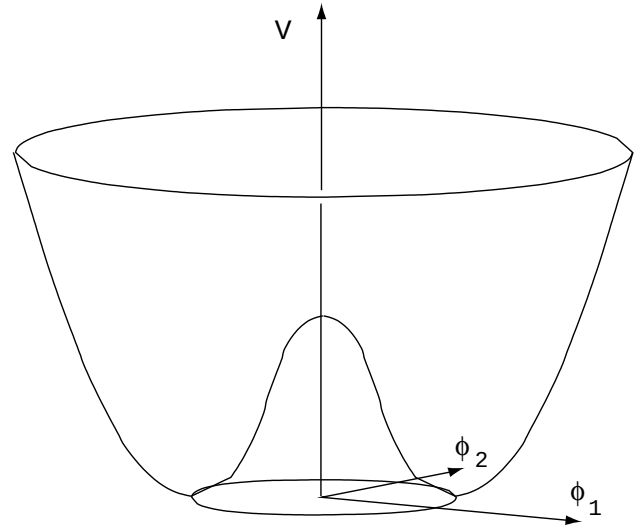
Spontaneous symmetry breaking

- Complex scalar ϕ
- Potential

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

(η const)

- Symmetry breaking: ground state not rotationally symmetric

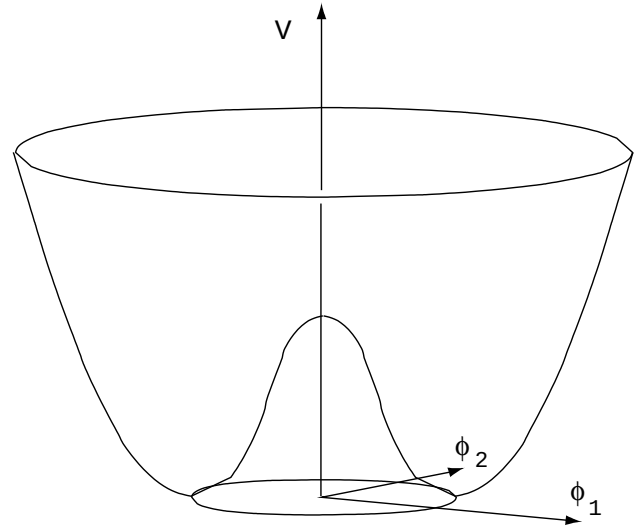


Spontaneous symmetry breaking

- Complex scalar ϕ
- Potential

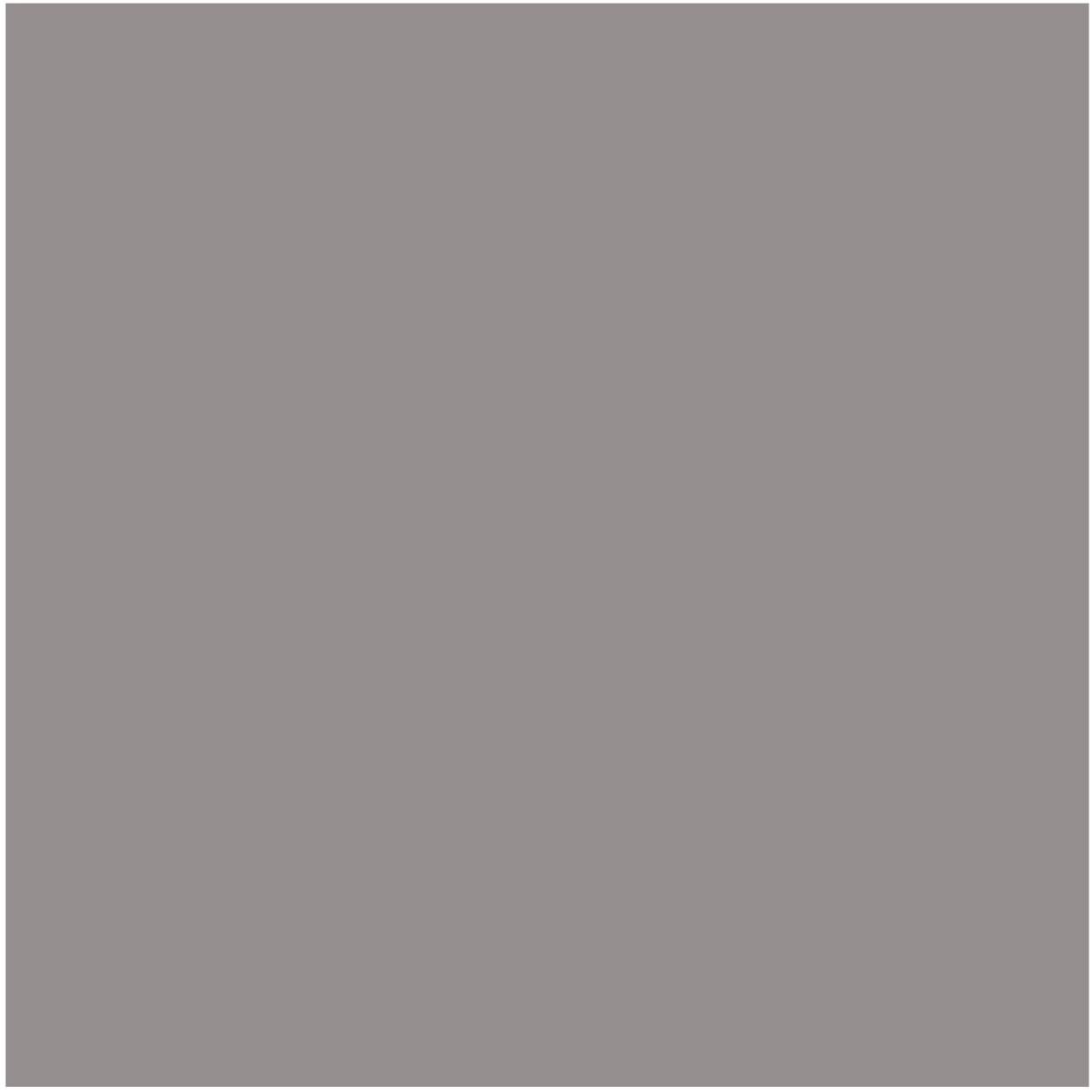
$$V \sim (|\phi|^2 - \eta^2)^2$$

(η const)

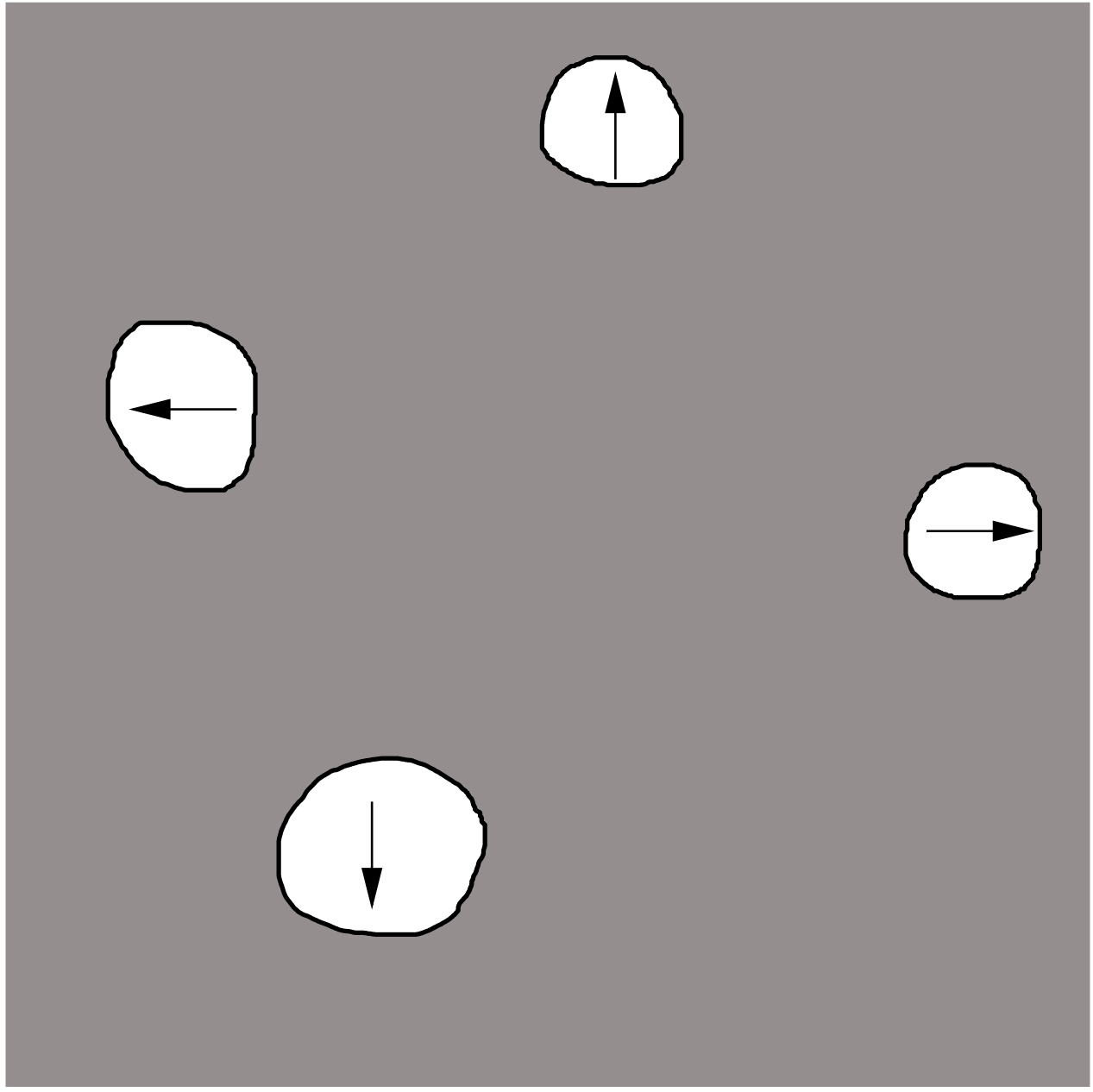


- Symmetry breaking: ground state not rotationally symmetric
- Effective potential temperature dependent
- High T: Symmetric ground state $\phi = 0$
- Symmetry breaking at critical T

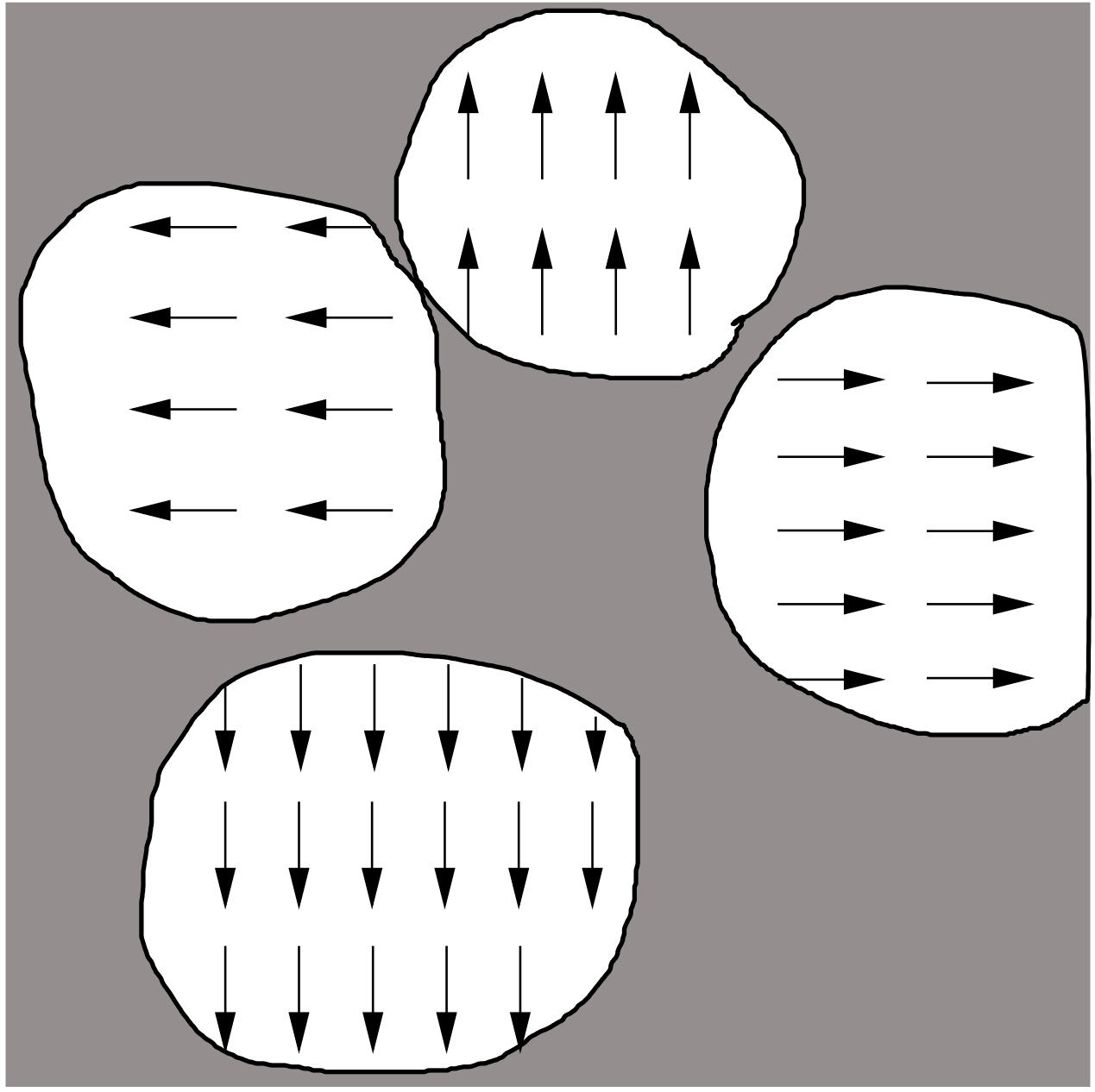
Early Universe



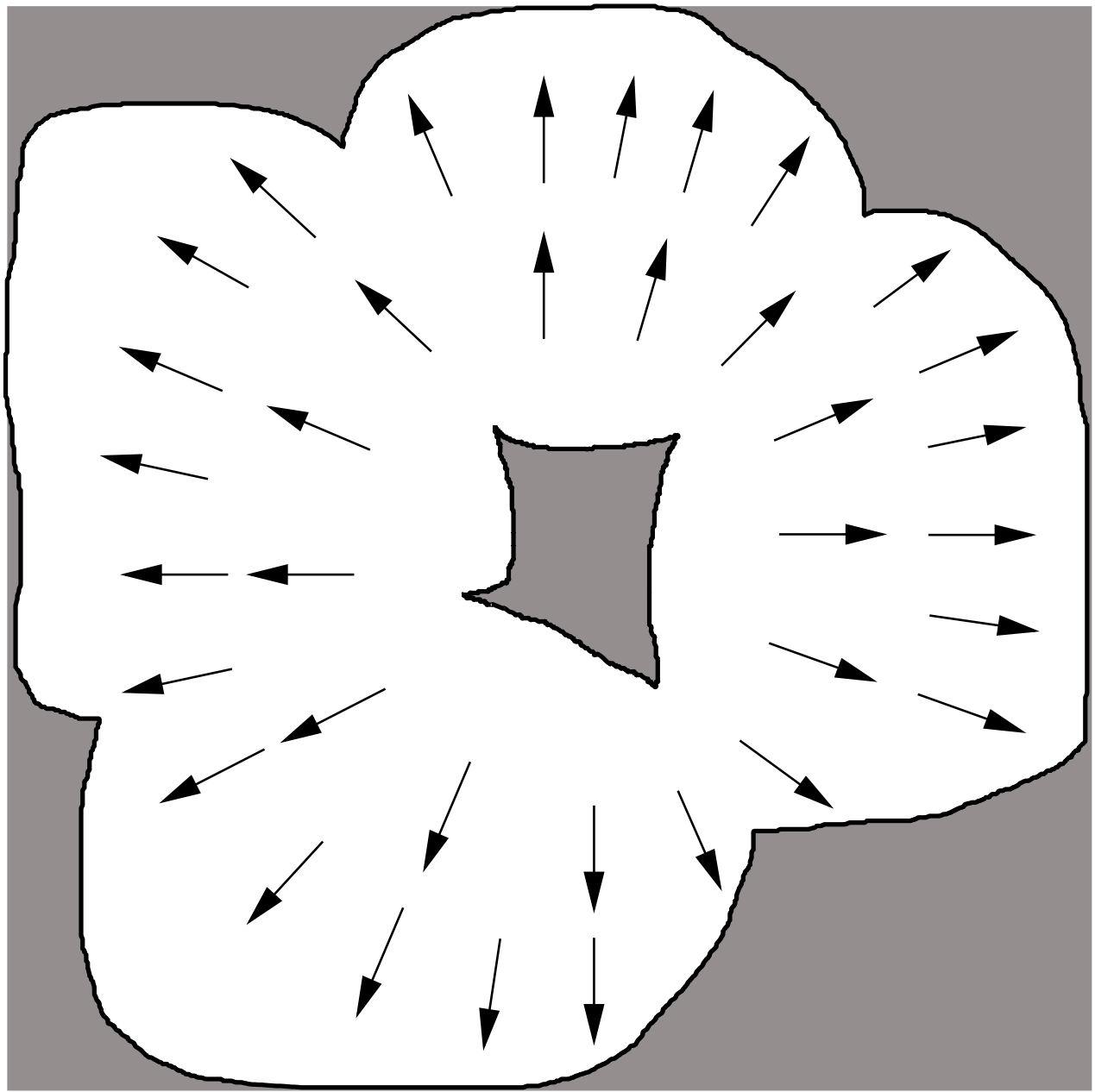
Early Universe



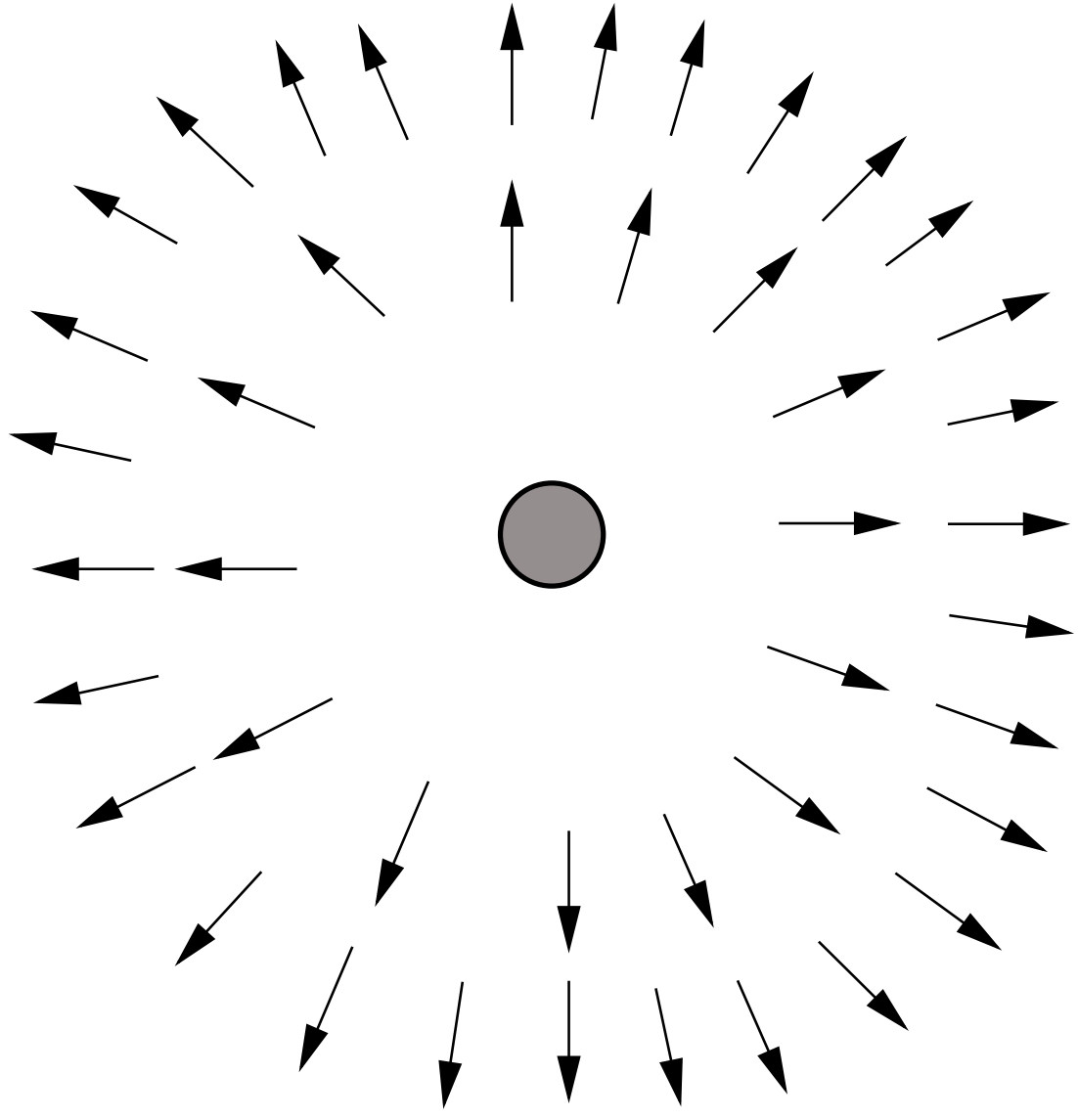
Early Universe



Early Universe



Early Universe



Strings and mass distribution

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

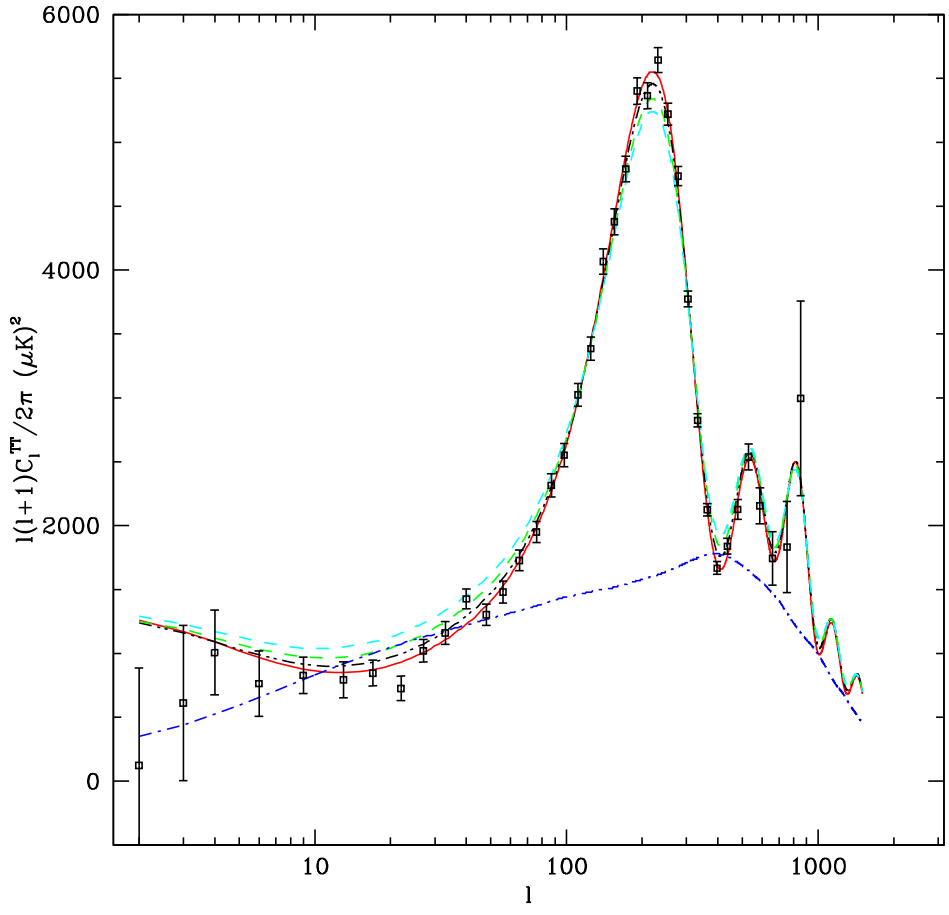
Strings and mass distribution

- Problem: How were the galaxies formed?
- Need fluctuations of mass density to start galaxy formation.
- Gravitational effect of strings $\sim G\mu \sim 10^{-6}$ (GUT-scale strings).
- $\rightsquigarrow$ Density fluctuations with $\delta\rho/\rho \sim 10^{-6}$ – might explain early galaxy formation.

Strings and mass distribution

- Problem: How were the galaxies formed?
- Need fluctuations of mass density to start galaxy formation.
- Gravitational effect of strings $\sim G\mu \sim 10^{-6}$ (GUT-scale strings).
- $\rightsquigarrow$ Density fluctuations with $\delta\rho/\rho \sim 10^{-6}$ – might explain early galaxy formation.
- Alternative: inflation. . .

Cosmic strings and CMB

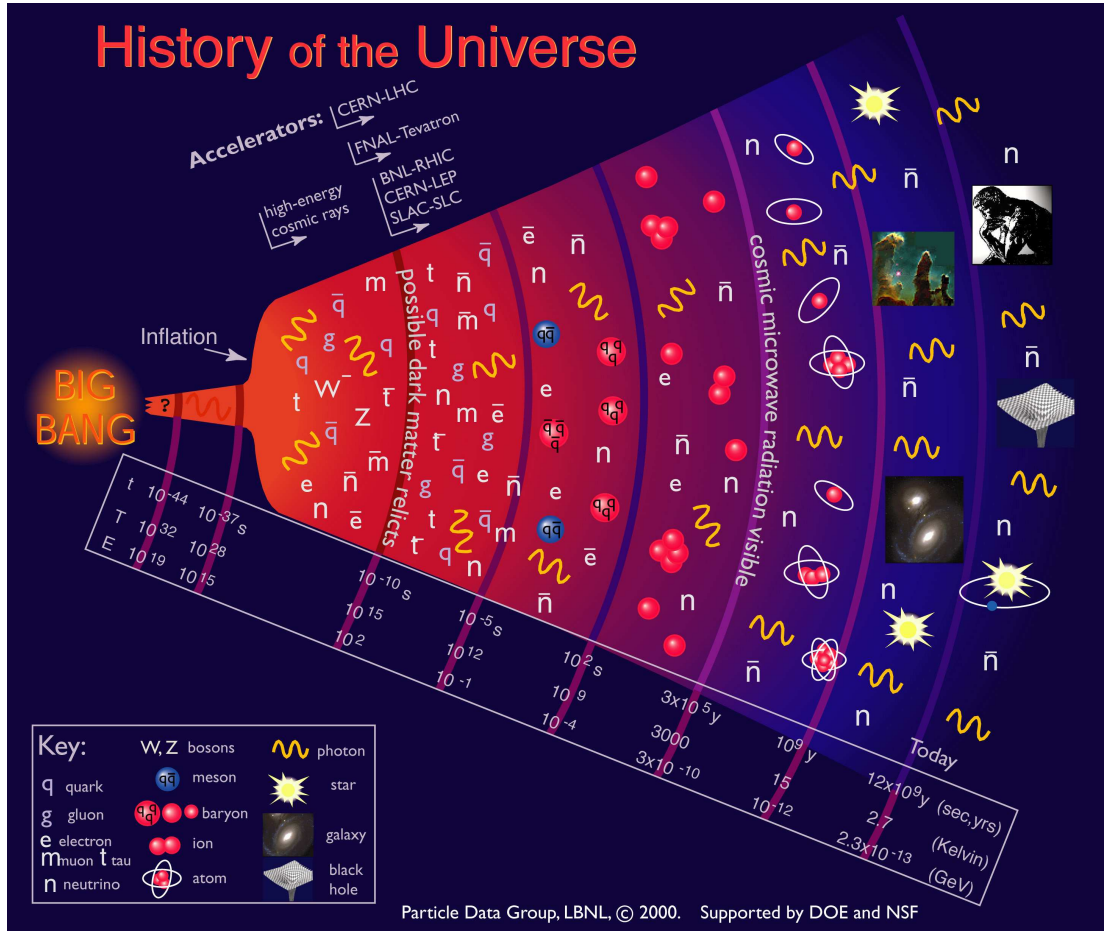


The WMAP satellite has measured the fluctuations in the cosmic microwave background radiation (CMB). Looks bad for strings. . .

[hep-th/0505050]

String theory and cosmic strings

- Cosmic strings may still exists
- F- and D-strings from before inflation may be big now



Brane-world models

- Our universe is a D3 brane
- “Large” extra dimensions: $\mu \mapsto \mu/V$
- “Warp factor”: $\mu \mapsto e^{2A}\mu$

Brane-world models

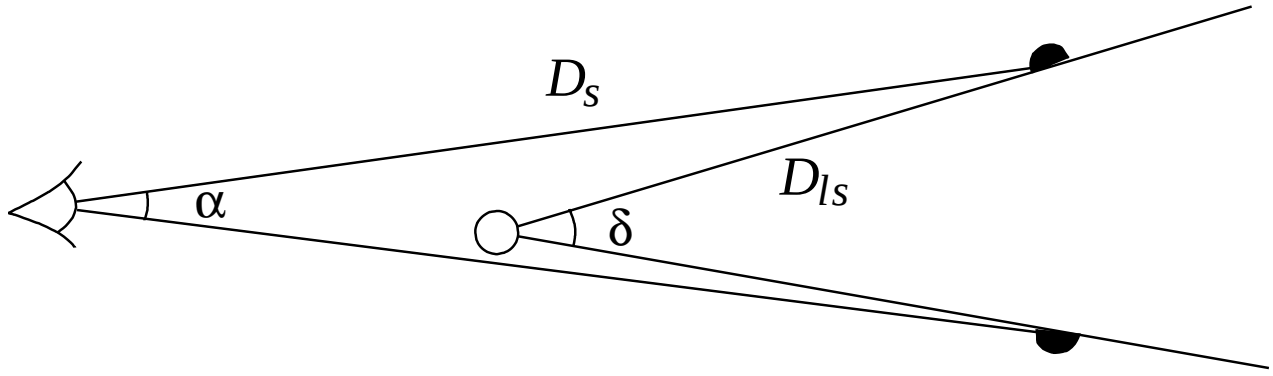
- Our universe is a D3 brane
- "Large" extra dimensions: $\mu \mapsto \mu/V$
- "Warp factor": $\mu \mapsto e^{2A}\mu$

Inflation:

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

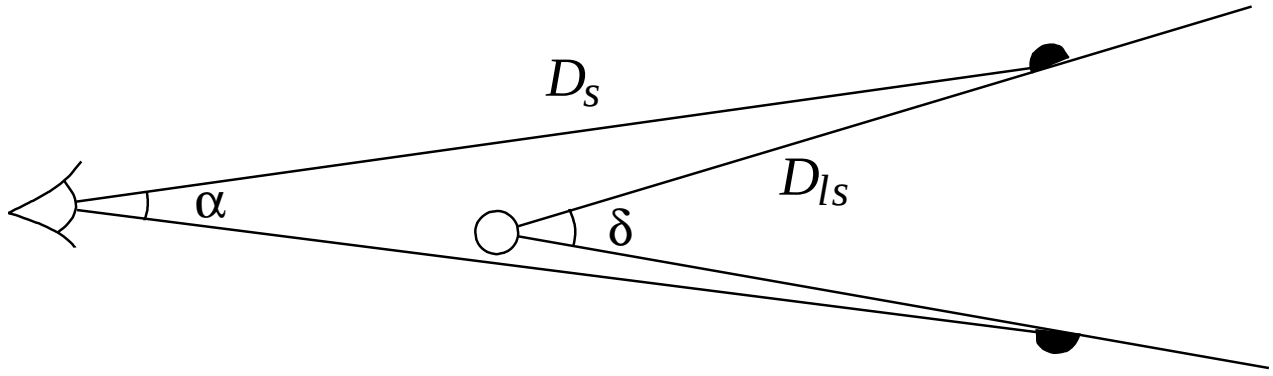
Observations

Lensing effect of string

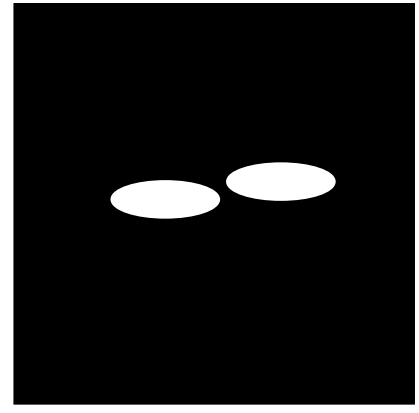


- $\delta = 8\pi G\mu$
- Can compute α from D_s and D_{ls}.

Lensing effect of string

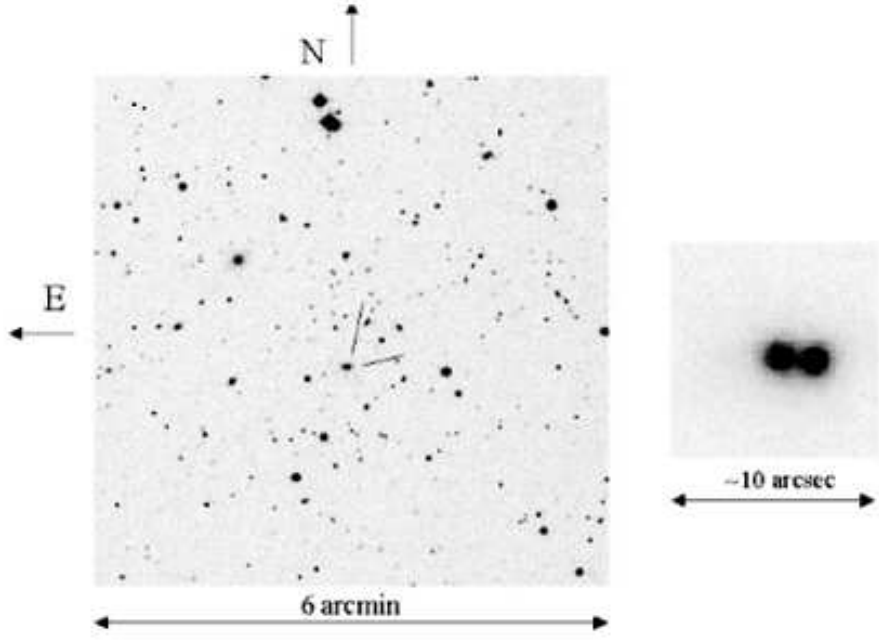


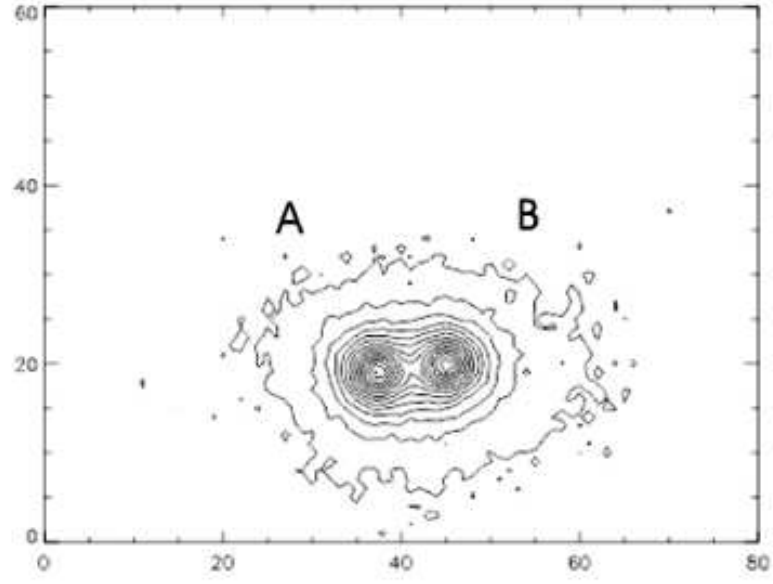
- $\delta = 8\pi G\mu$
- Can compute α from D_s and D_{ls}.



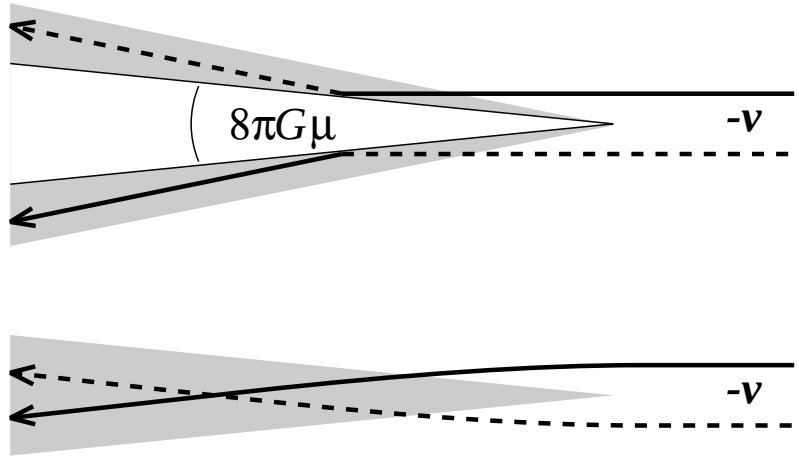
CSL-1

- “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]



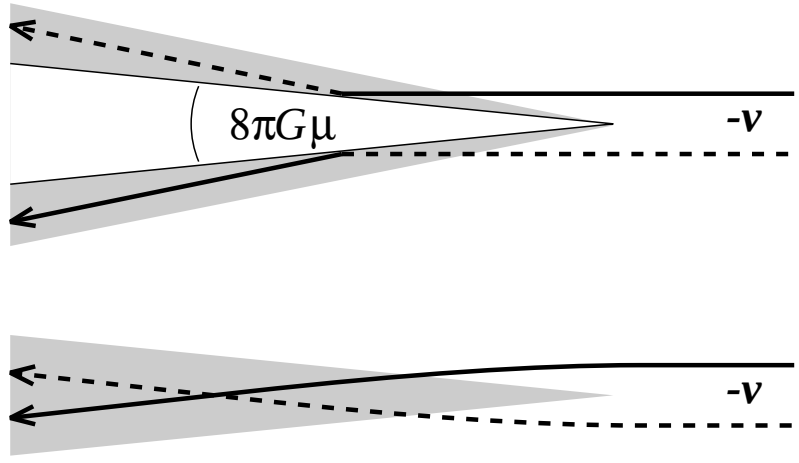


Edges in CMB



- Discontinuity in redshift at string $\Rightarrow$ “edge”
- A. S. Lo, E. L. Wright, [astro-ph/0503120], looked for edges in WMAP data
- No clear evidence of strings

Edges in CMB



- Discontinuity in redshift at string $\Rightarrow$ “edge”
- A. S. Lo, E. L. Wright, [astro-ph/0503120], looked for edges in WMAP data
- 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

Astron.Astrophys. 422 (2004) 477-482 [astro-ph/0406434]

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

Summary

- String theory assumes elementary particles are tiny strings
- The theory implies existence of D-branes and D-strings
- Cosmic strings appear from spontaneous symmetry breaking in early universe
- Huge F- and D-strings may be created by inflation
- No definitine observations (yet?), but some claims. . .

Popular references on string theory:

- Brian Greene: *The Elegant Universe*
  TV series, see: *http://www.pbs.org/wgbh/nova/elegant/*
- *http://superstringtheory.com/*