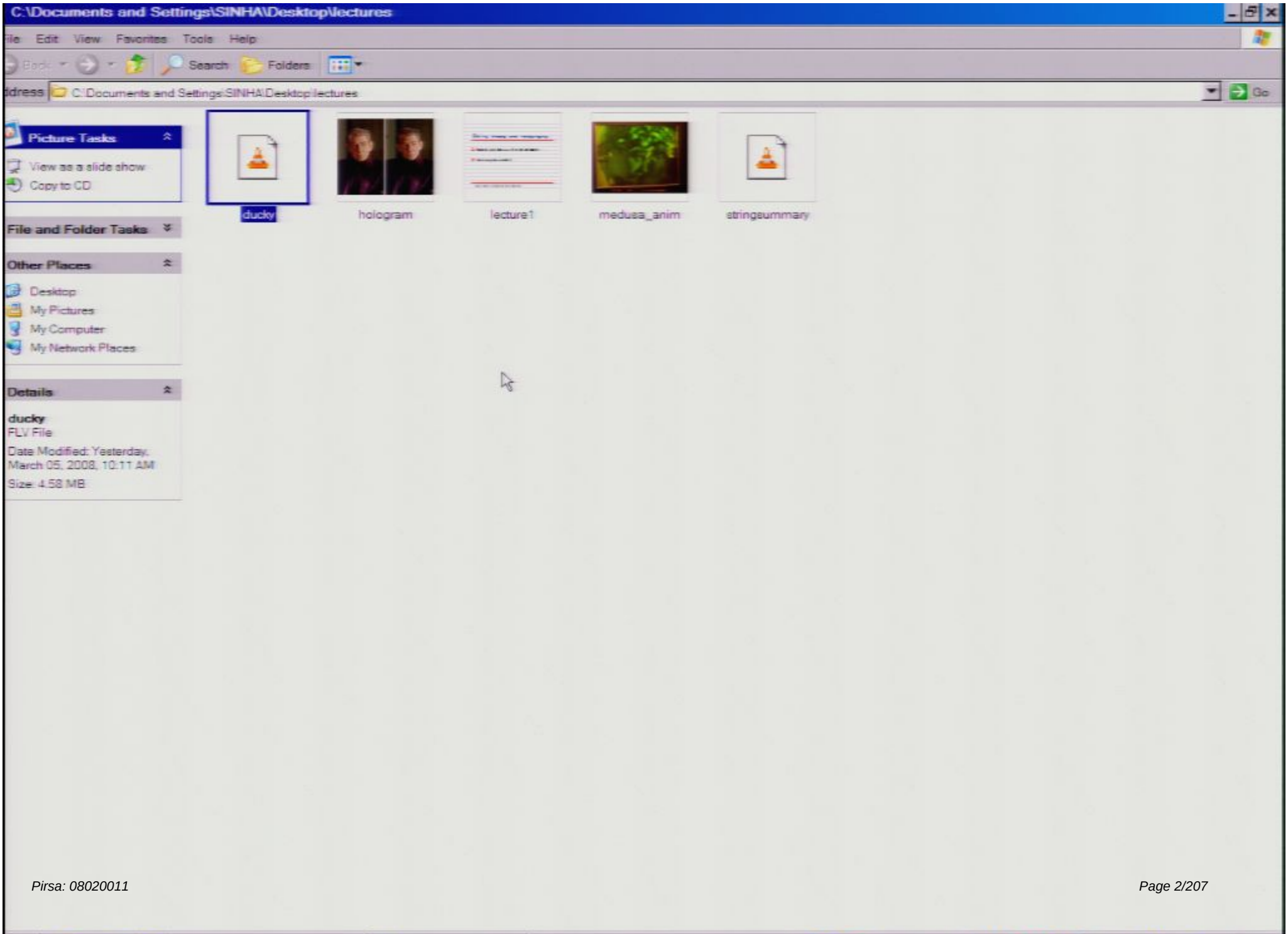
Title: String Theory #5 & 6

Date: Mar 06, 2008 06:30 PM

URL: http://pirsa.org/08020011

Abstract: Strings vs. particles. Branes and Holography in quantum gravity.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String theory and holography

- Holography ideas will be introduced
- No examples sheet !!

String theory and holography

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Some basic ideas

Planck units

Planck units are units of length(l_P), mass(m_P), time (t_P), charge (q_P) and temperature (T_P) constructed out of c, G, $\hbar$, $4\pi\varepsilon_0$, k.

Physical significance: m_P is the mass for which Schwarzschild radius is the same as the Compton wavelength. This is the energy scale at which QUANTUM PROPERTIES are comparable with the GENERAL RELATIVISTIC PROPERTIES of the particle.

$$m_P = \sqrt{\frac{\hbar c}{G}} \approx 10^{19} GeV/c^2 \approx 2.18 \times 10^{-8}\ kg$$

$$l_P = \sqrt{\frac{\hbar G}{c^3}} \approx 10^{-35} m$$

Mass of a flea is 5000 m_P but size is 10^{33} l_P

No problem set this week.

$$ds^2 = -\left(1 - 2\frac{GM}{c^2 r}\right)dt^2 + \left(1 - 2\frac{GM}{c^2 r}\right)^{-1} dr^2 + r^2 d\Omega_2^2$$

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$$R_s = \frac{2GM}{c^2}$$

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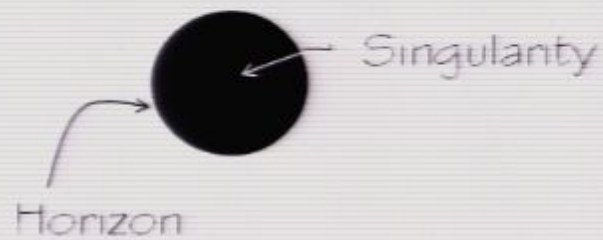
A quick review of some basics

Black holes have entropy

$$S_{BH} = \frac{kA}{4l_P^2}$$

!!!

Planck length



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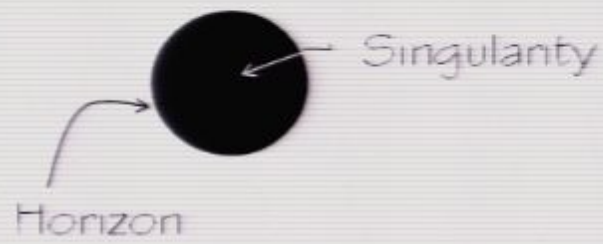

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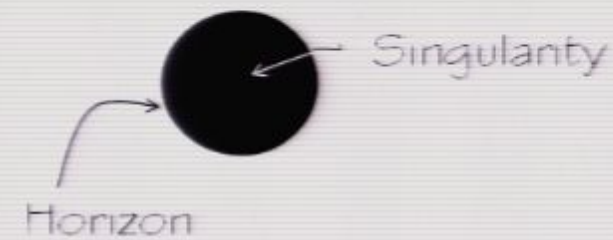

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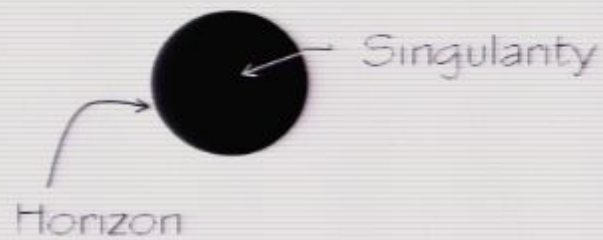

Also have microscopic description of entropy

$$S_{micro} = k \ln \Omega$$

Ω= no. of microscopic configurations resulting in observed macroscopic description

Q: How to calculate Ω?

A: Use **string theory**

Some buzz words

- QFT: Quantum field theory which is a theoretical framework for constructing quantum mechanical models of field like systems or many body systems.
- CFT: Conformal field theory is a QFT that is invariant under a special symmetry called conformal symmetry.
- QCD: Quantum ChromoDynamics. Theory of strong force.
- Colour: Something like electric charge, present in quarks, gluons.
- UV/IR: UV—ultra-violet, IR– infra-red. UV corresponds to high energy/ short wavelengths, IR corresponds to low energy/ long wavelengths
- Perturbation theory: Will explain on black board.
- Coupling constant: Something that measures the strength of an interaction and needs to be small for perturbation theory methods to be valid.
- Gauge symmetry: A special kind of symmetry. Standard model has SU(3) x SU(2) x U(1) gauge group.
- Supersymmetry: A special symmetry saying that the number of bosons and fermions are same at each energy level.

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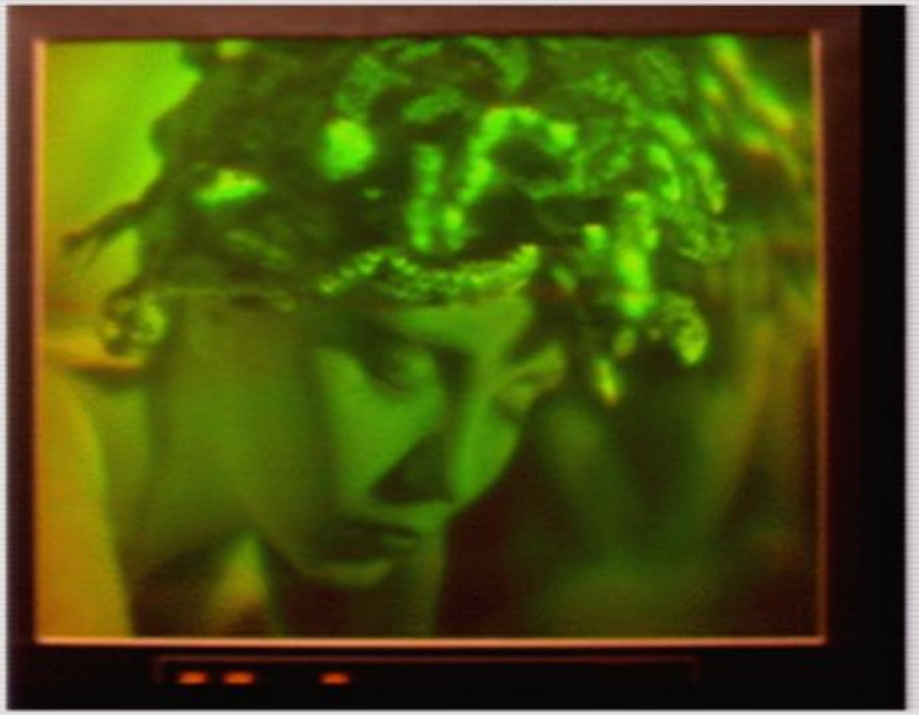
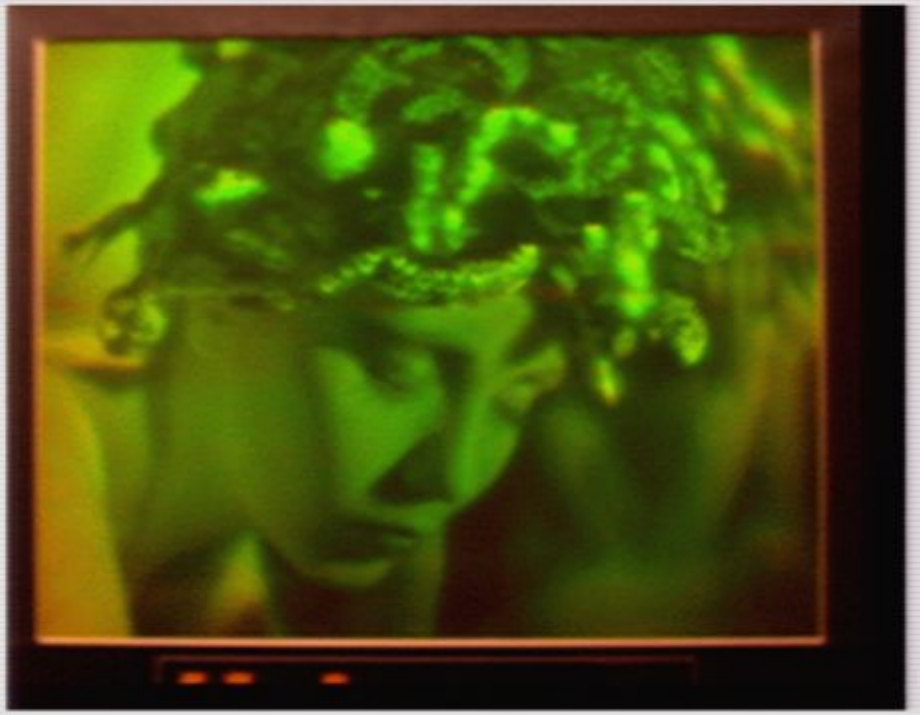
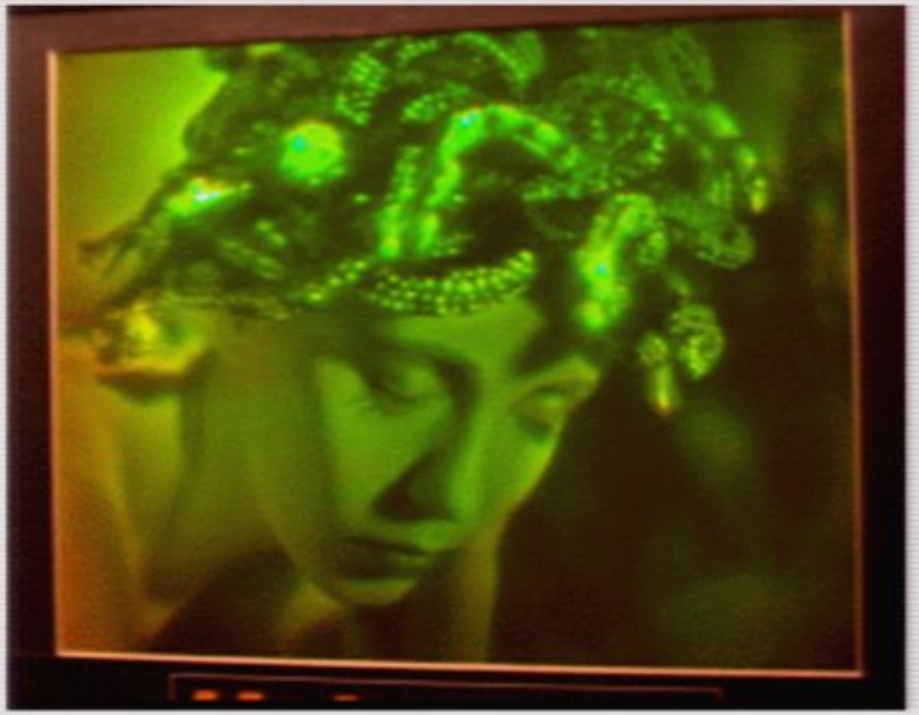
$\lambda \to$ Coupling constant

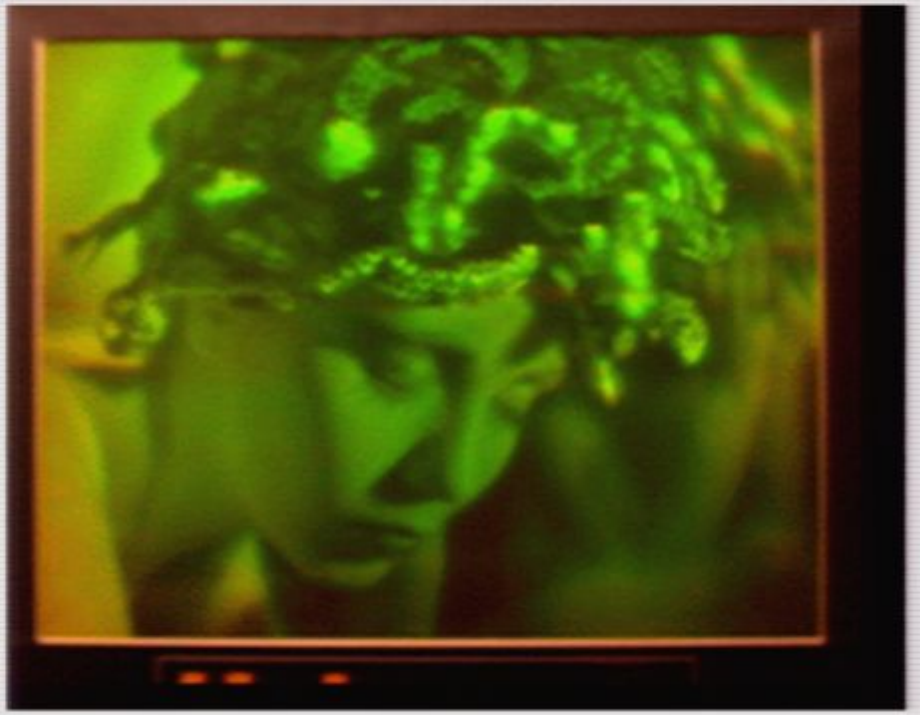
Hologram

Hologram









Compared to conventional photographs a hologram is able to record 3-dimensional information.

It achieves so by recording the relative phases of coherent light reflected from the object.

Thus it in effect stores 3 dimensional information on a 2 dimensional surface.

An analogous idea prevails in quantum gravity and goes by the name of **HOLOGRAPHY.**

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Source: The Illusion of Gravity by Juan Maldacena in Scientific American

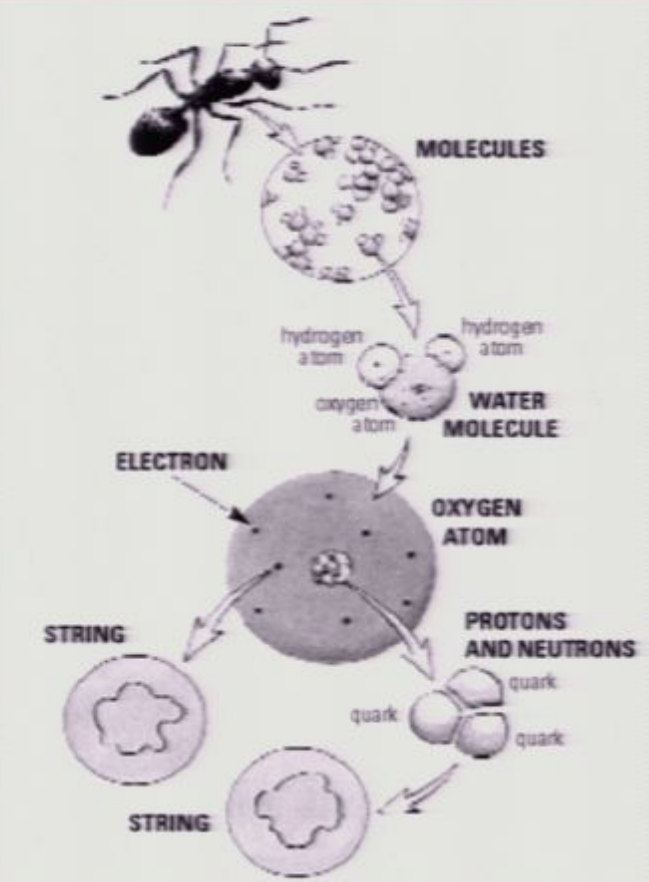
HOLOGRAPHIC THEORY relates one set of physical laws acting in a volume with a different set of physical laws acting on a boundary surface, as represented here by the juggler and her colorful two-dimensional image. The surface laws involve quantum particles that have "color" charges and interact very like the quarks and gluons of standard particle physics. The interior laws are a form of string theory and include the force of gravity (experienced by the juggler), which is hard to describe in terms of quantum mechanics. Nevertheless, the physics on the surface and in the interior are completely equivalent, despite their radically different descriptions.

Some string theory basics

Origins of String Theory

Quick Timeline
1921 - Kaluza-Klein Theory
1970 - Birth of string theory
1971 - Supersymmetry
1973 - Quantum Chromodynamics
1974 - Gravitons as closed strings; advent of string theory as a unified theory
1976 - Supergravity; supersymmetry applied to gravity
1980 - Superstrings; supersymmetry applied to strings
1984 - First Revolution; anomalies are cancelled and string theory goes mainstream
1987 - E8xE8 Heterotic superstring theory that may explain dark matter
1993 - 't Hooft and Susskind introduce idea of holography
1994 - Second Revolution; D-branes, dualities
1996 - Black Hole Entropy; microscopic origin using string theory
1997 - AdS/CFT correspondence, concrete holographic realization

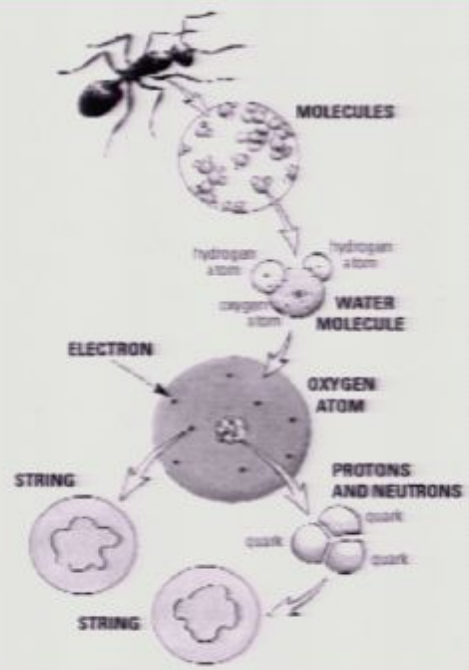
String theory: a quick summary



Movie 1

Movie 2

String theory: a quick summary



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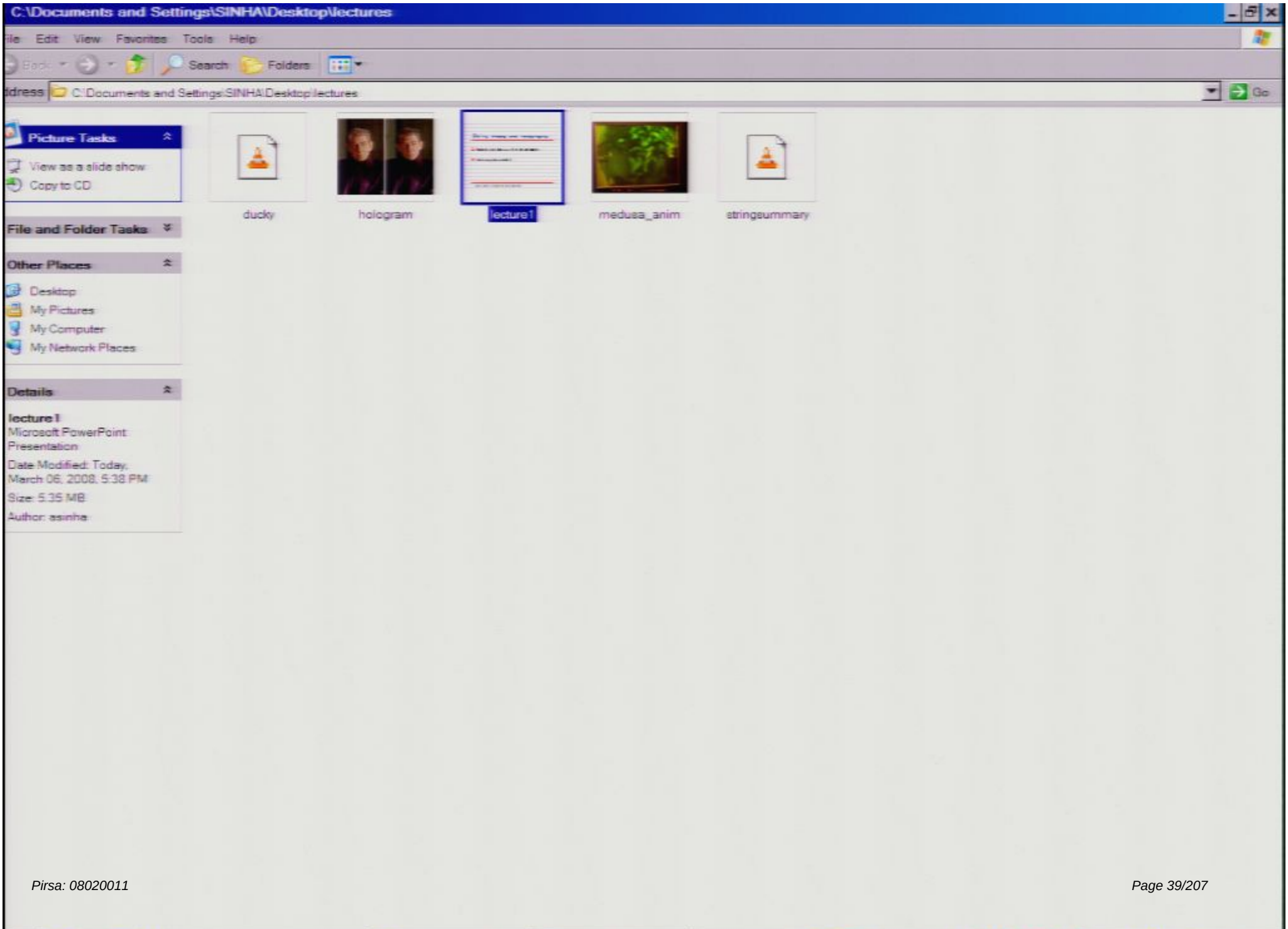
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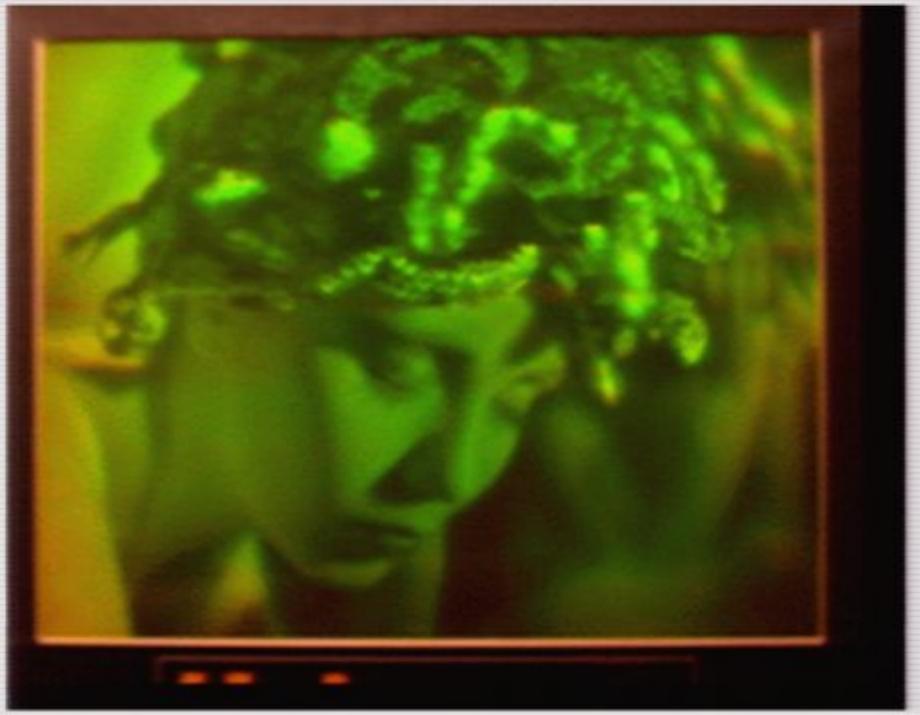
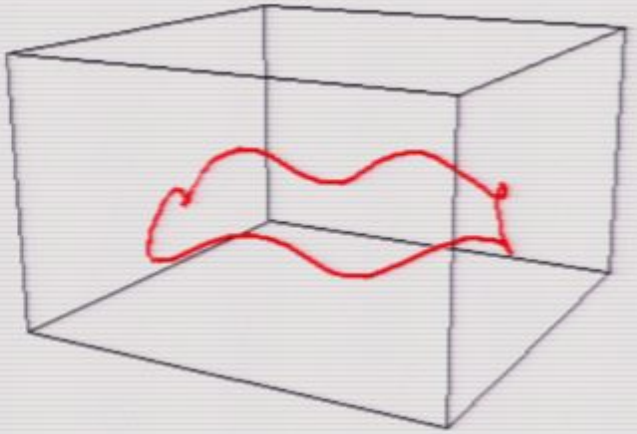


Fundamental strings





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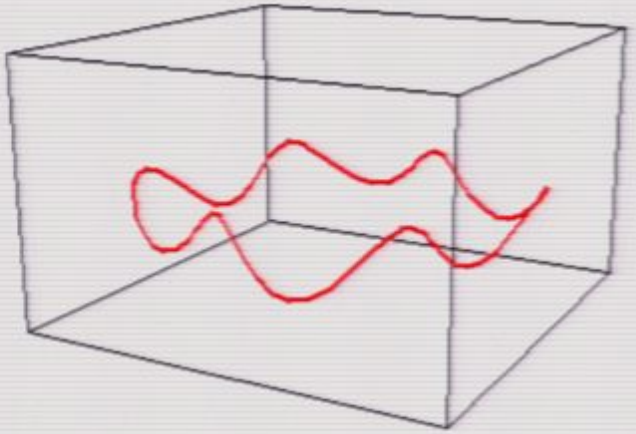
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings





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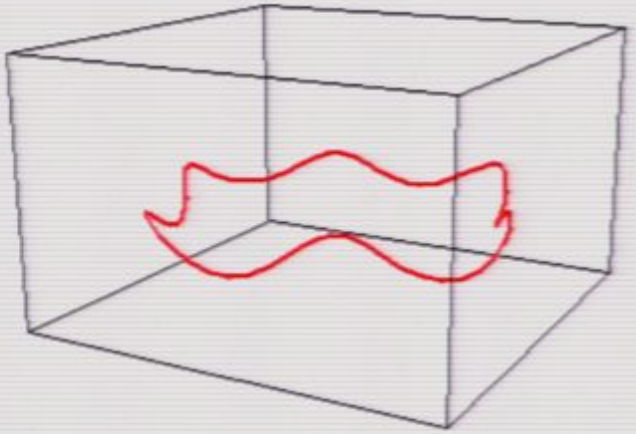

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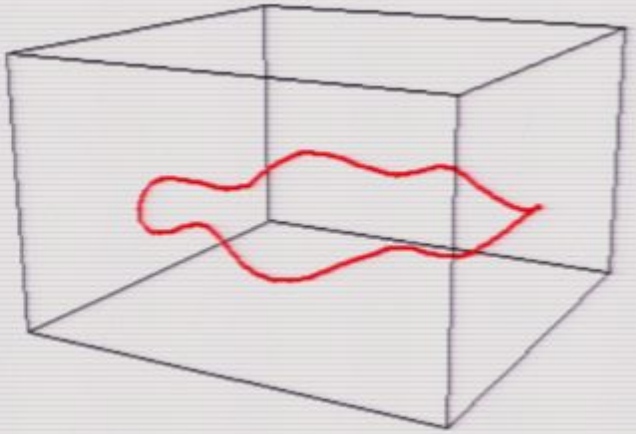

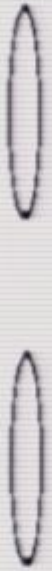

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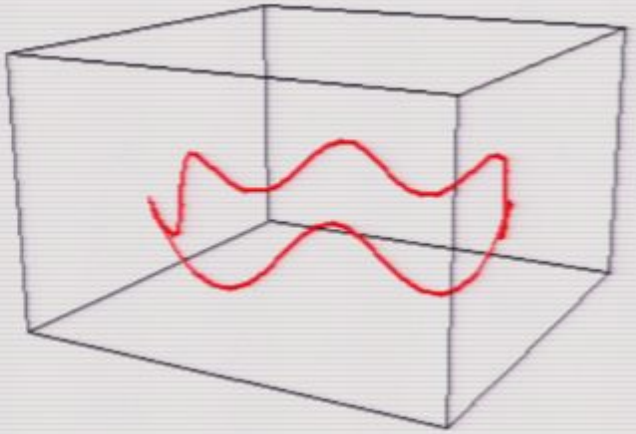

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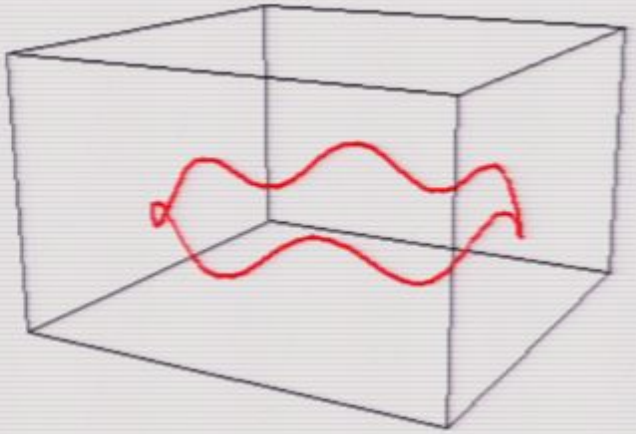

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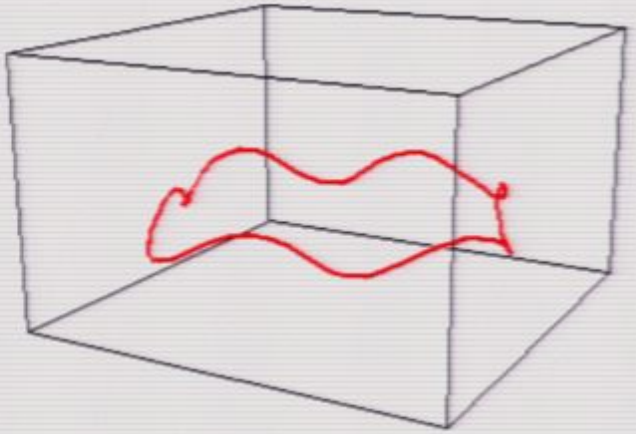

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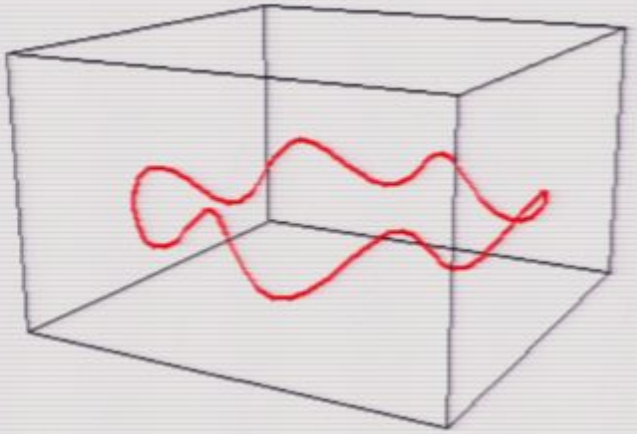

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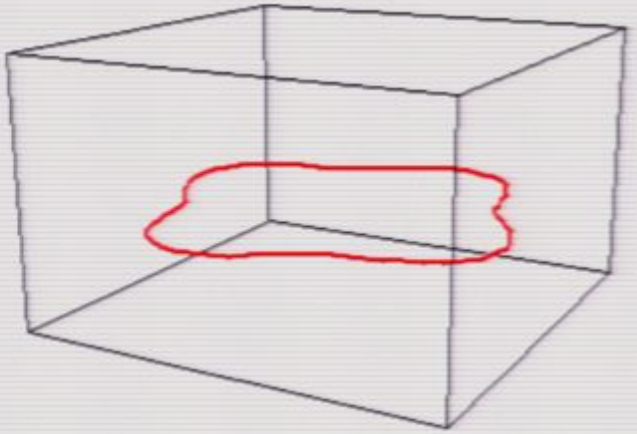

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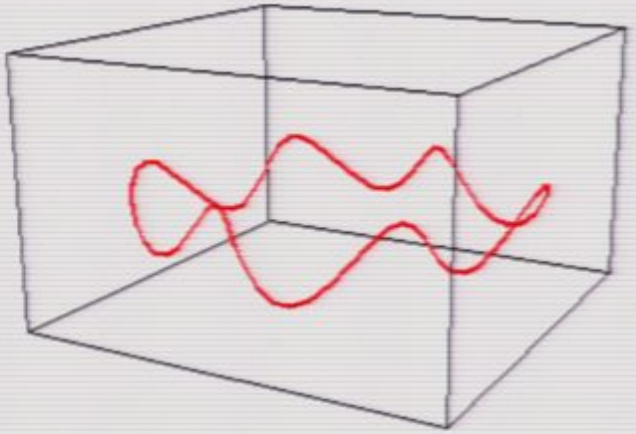

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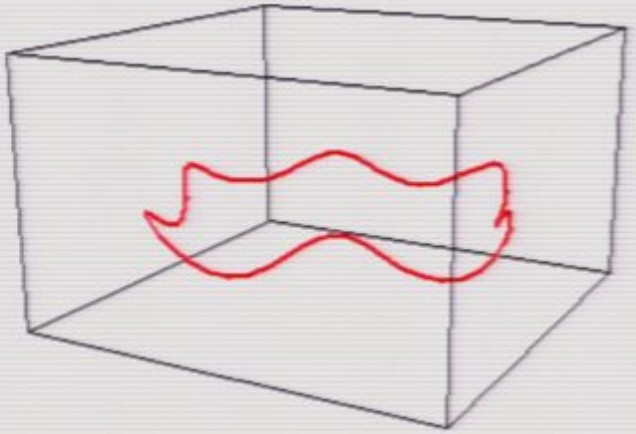

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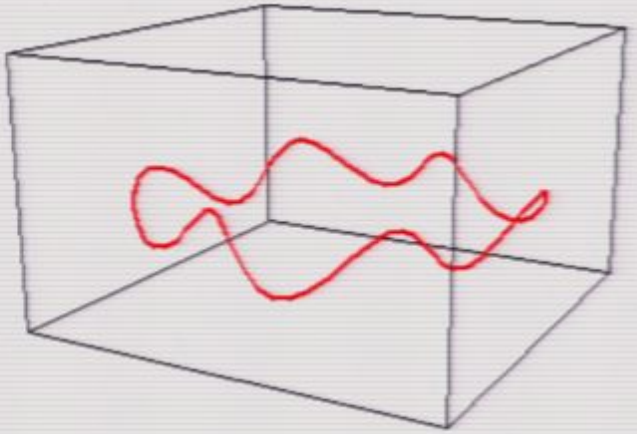

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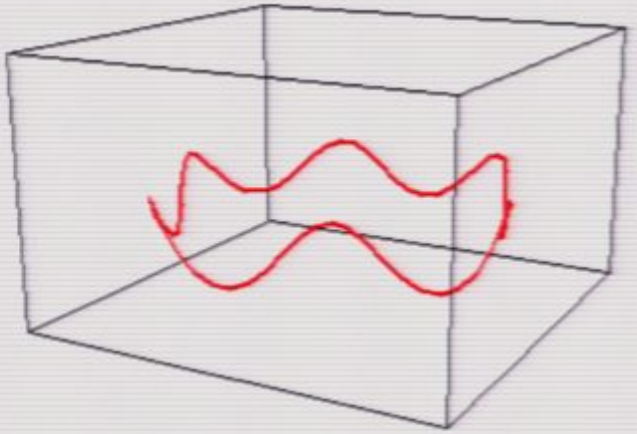

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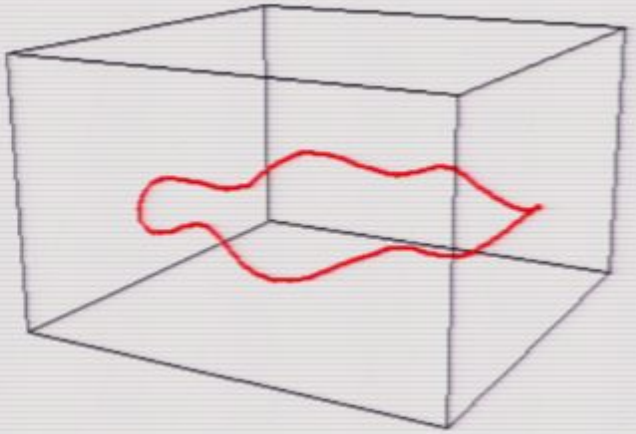

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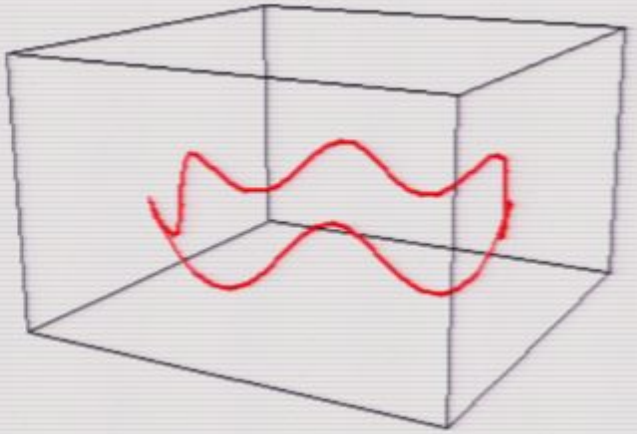

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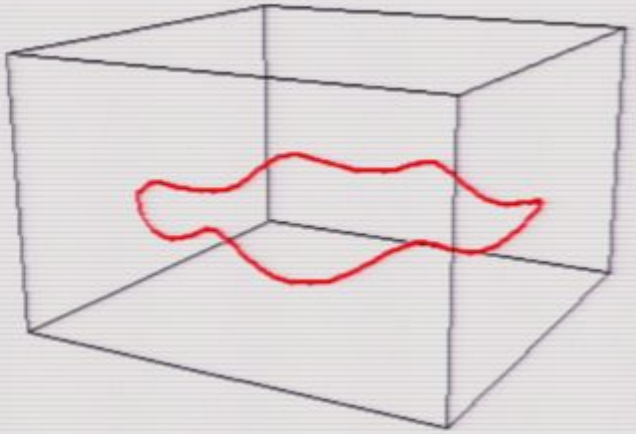

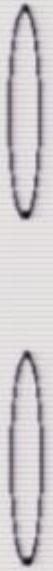

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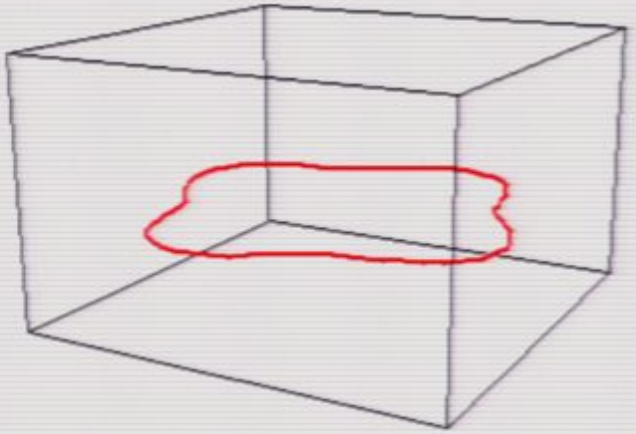

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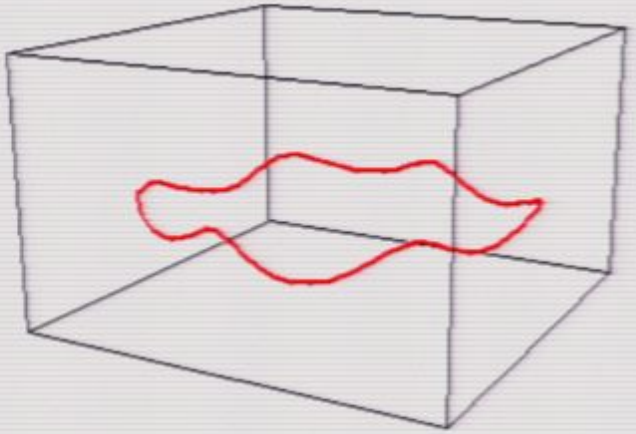

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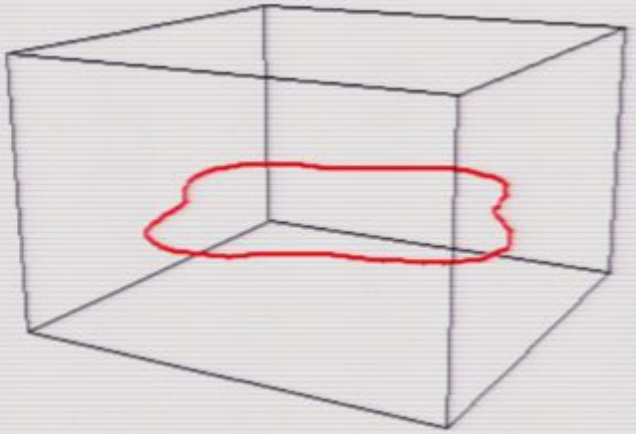

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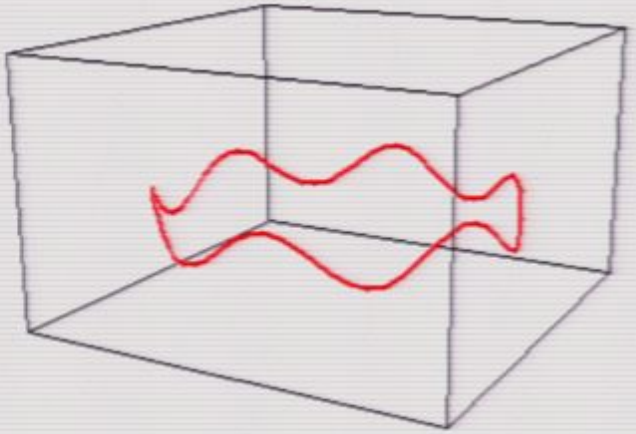

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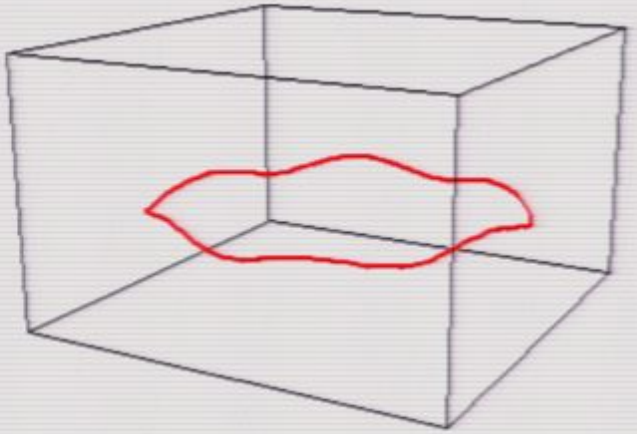
[generates modifications to GR!!]

Fundamental strings



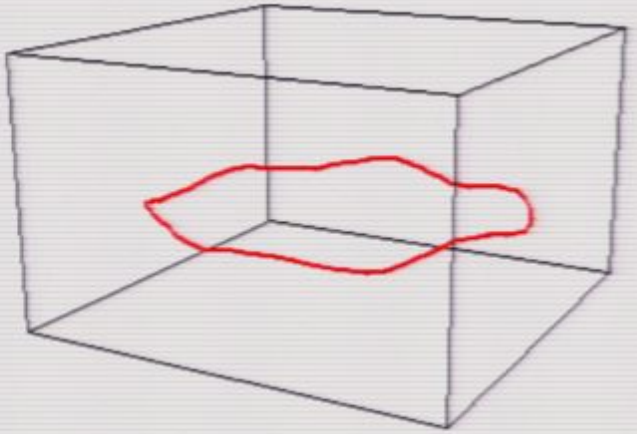


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



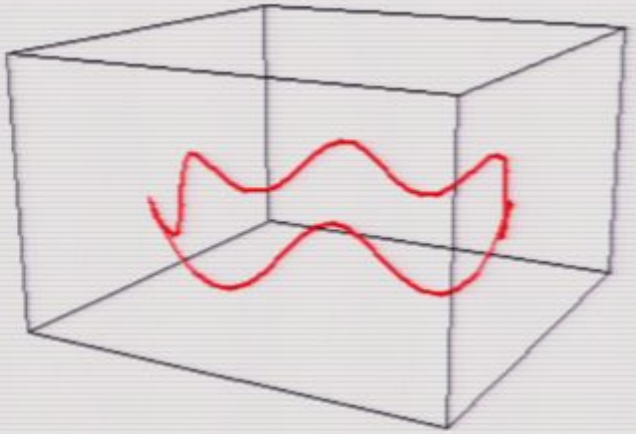


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



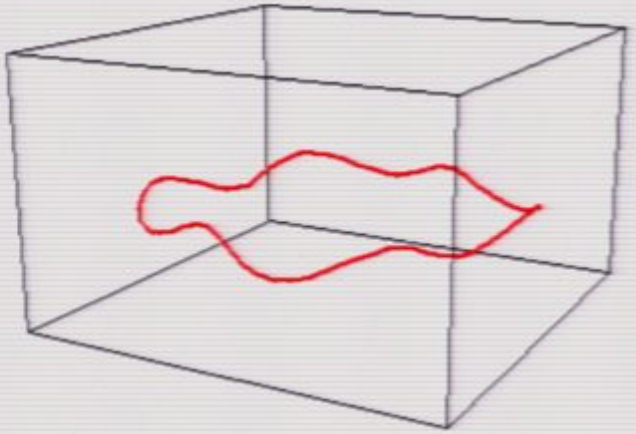


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



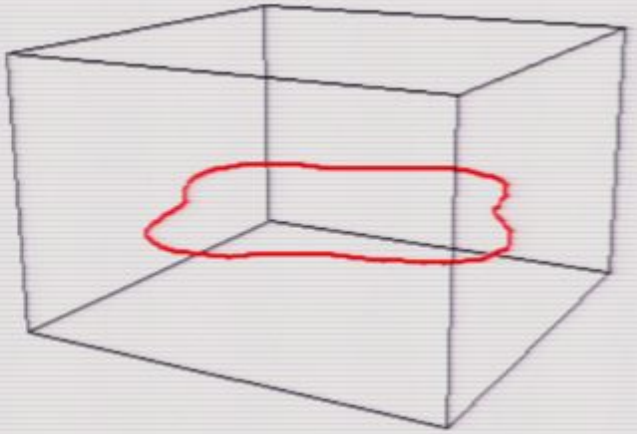


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



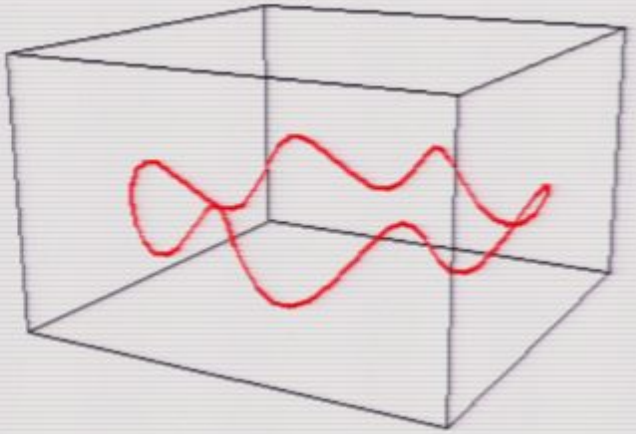


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



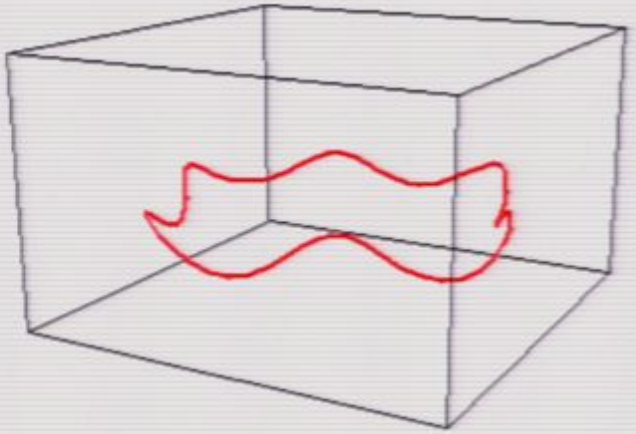


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



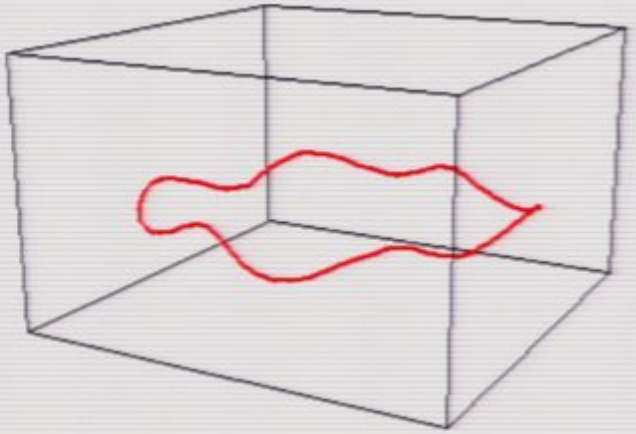


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



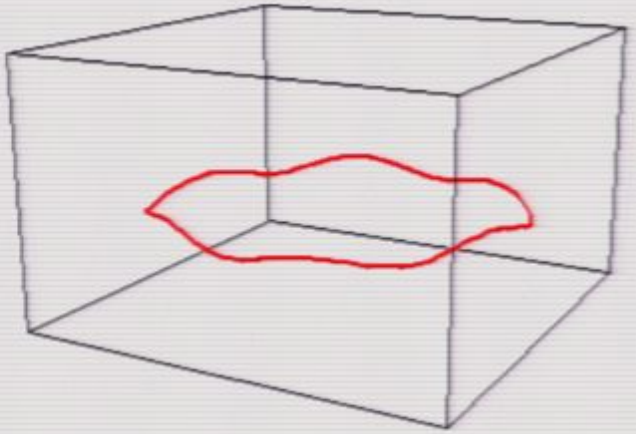


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



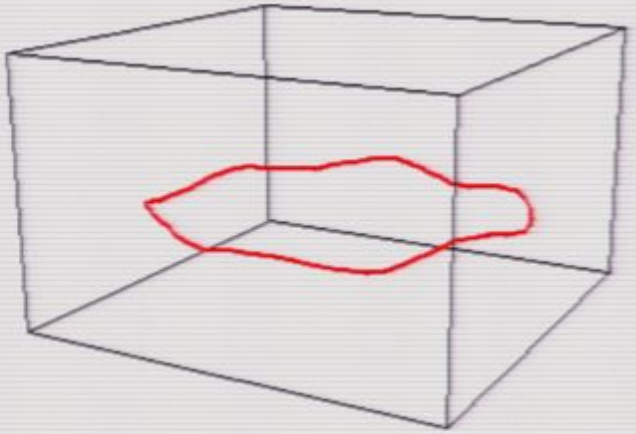


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



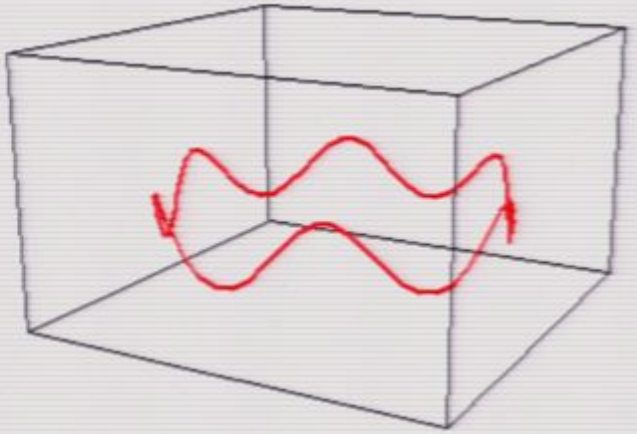


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



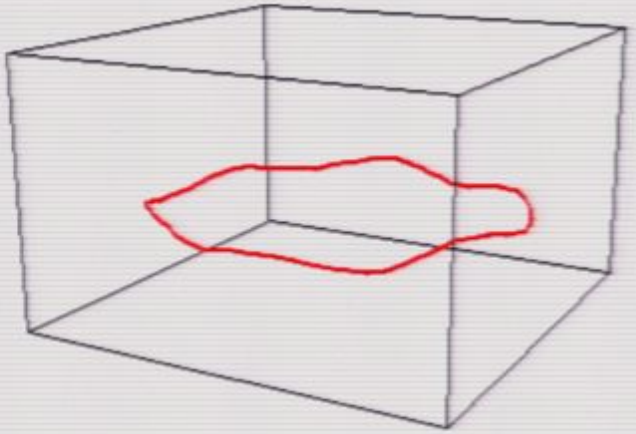


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



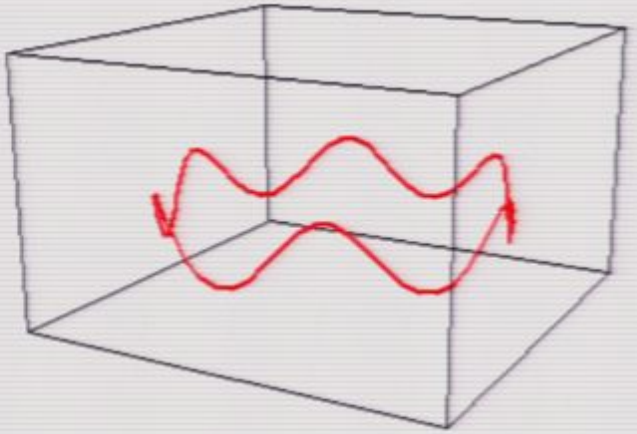


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



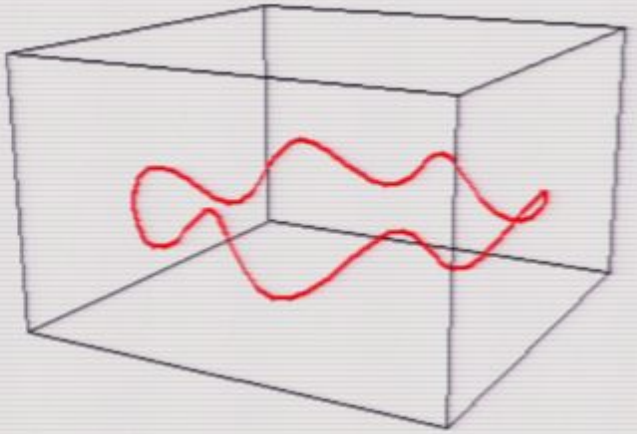


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



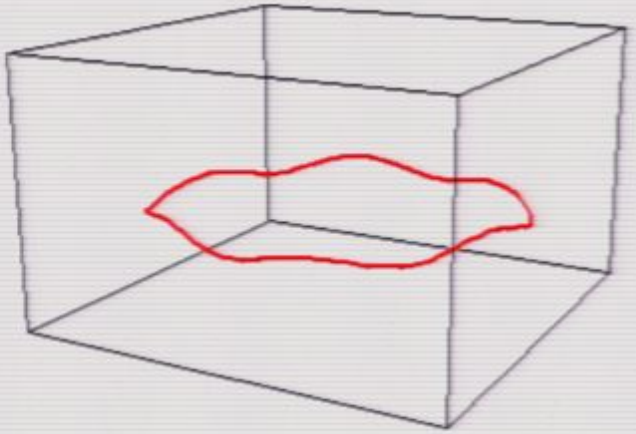


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



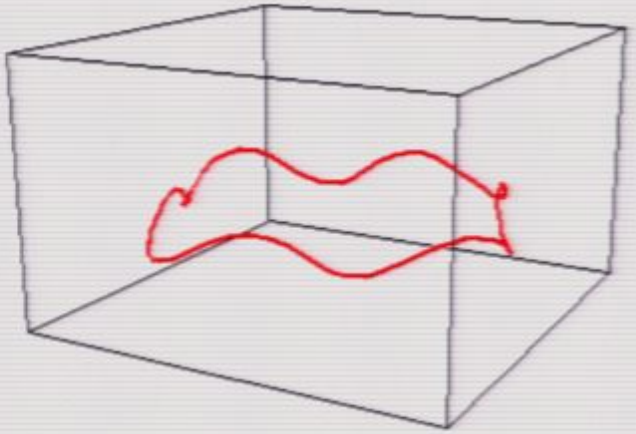


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



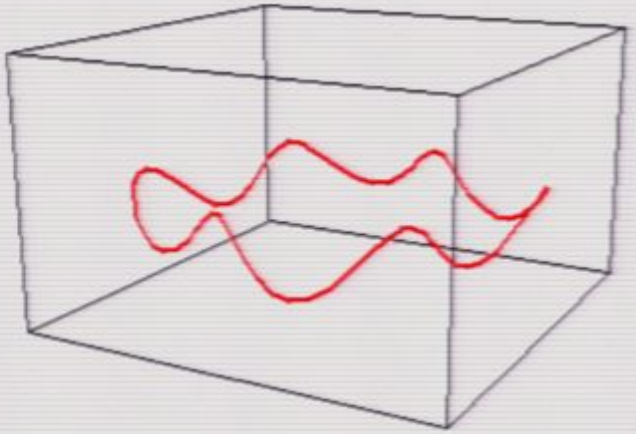


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



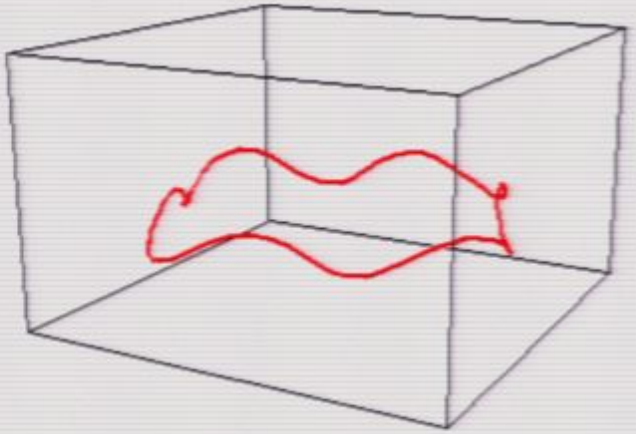


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



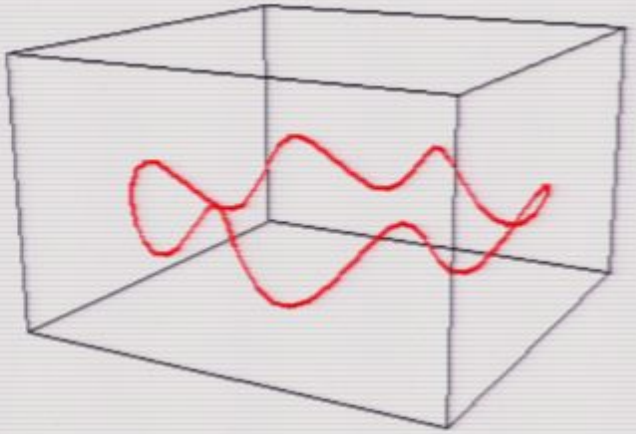


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



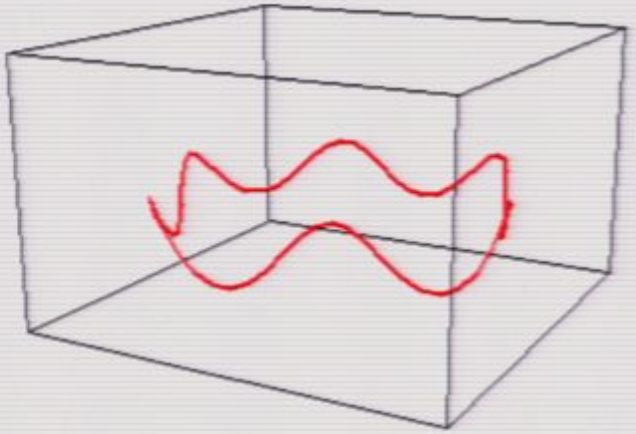


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



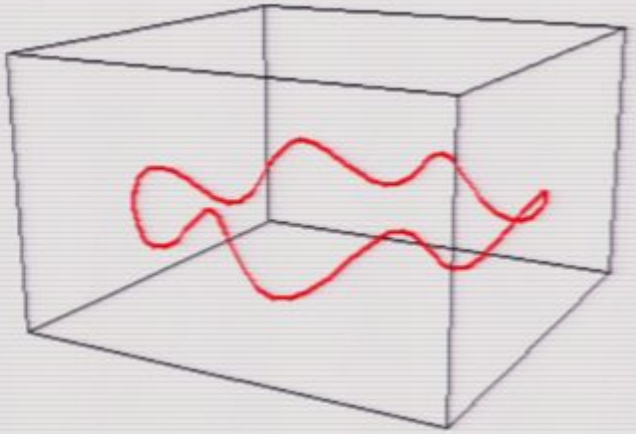


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



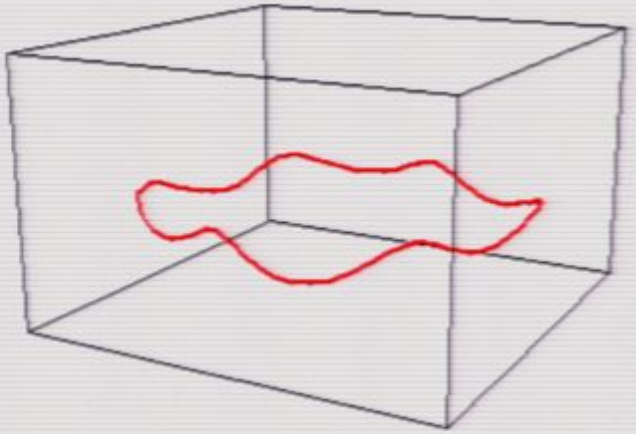


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



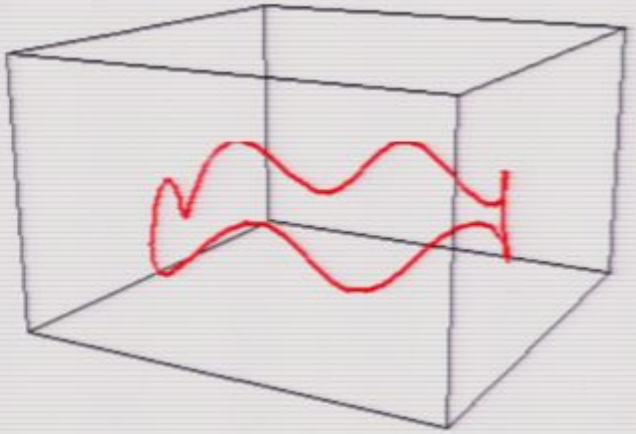


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



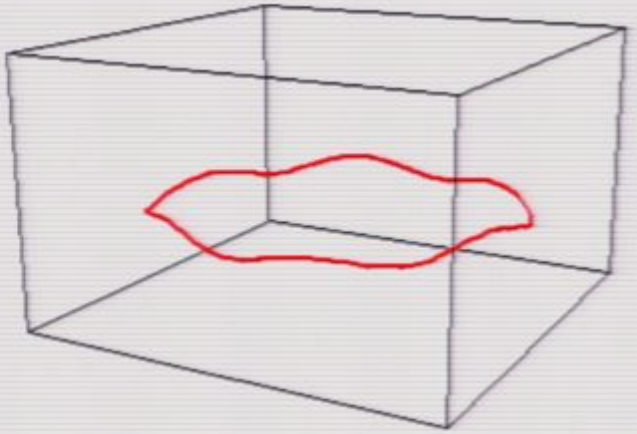


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



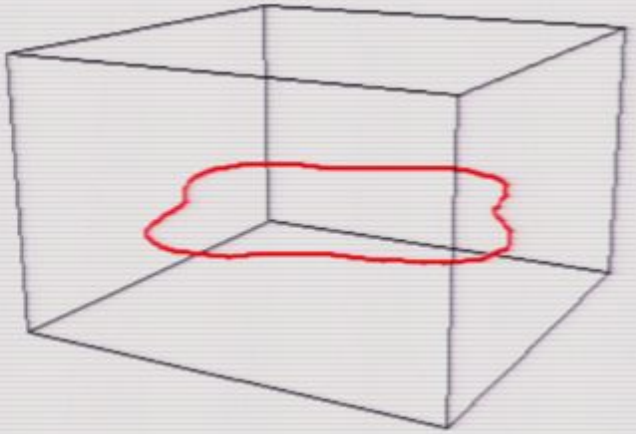


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



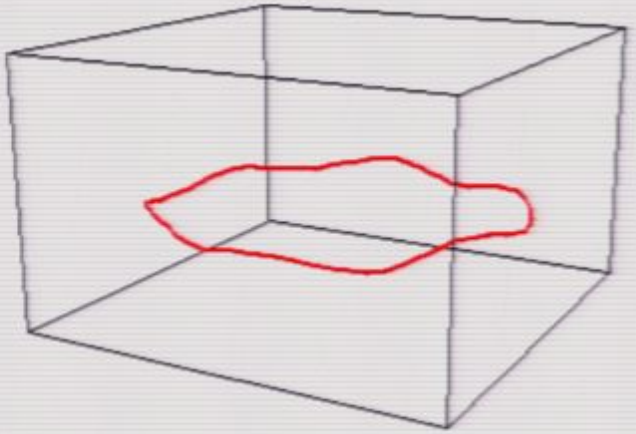


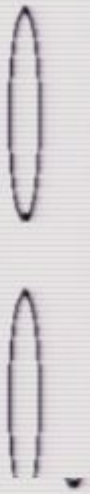
FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings





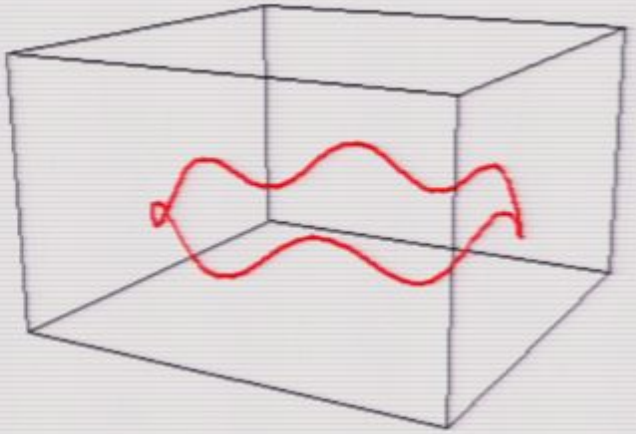


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



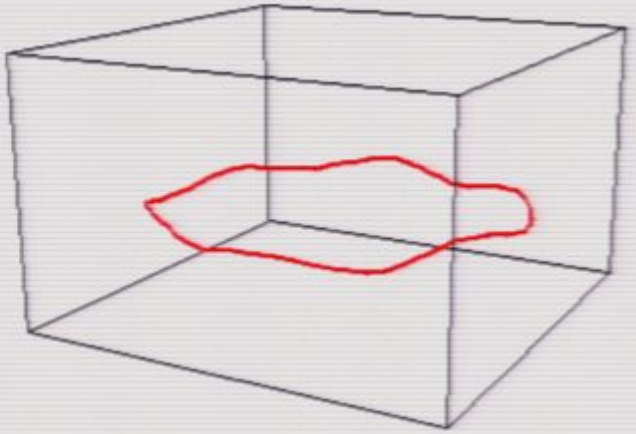


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



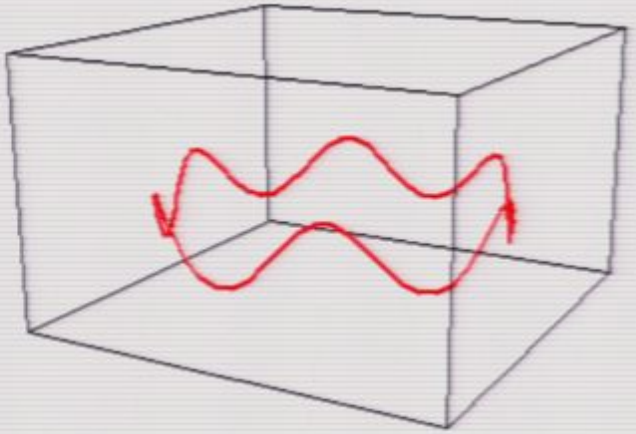


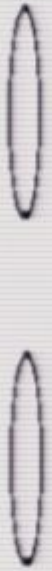
FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings





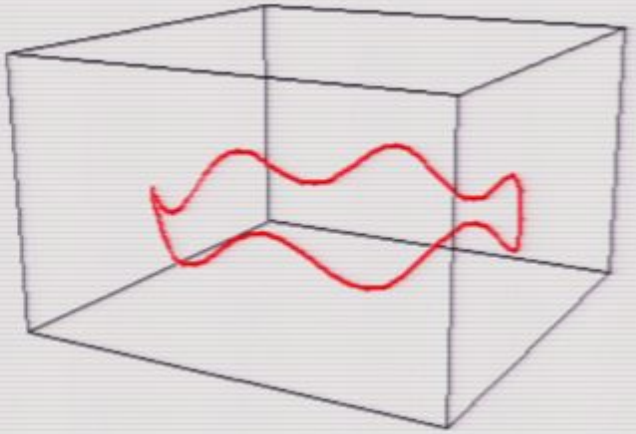


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



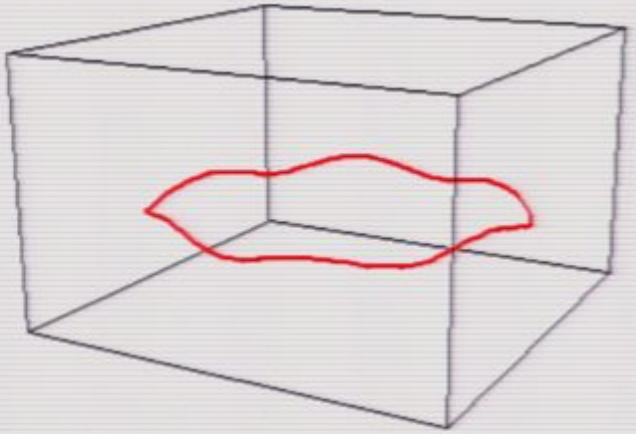


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



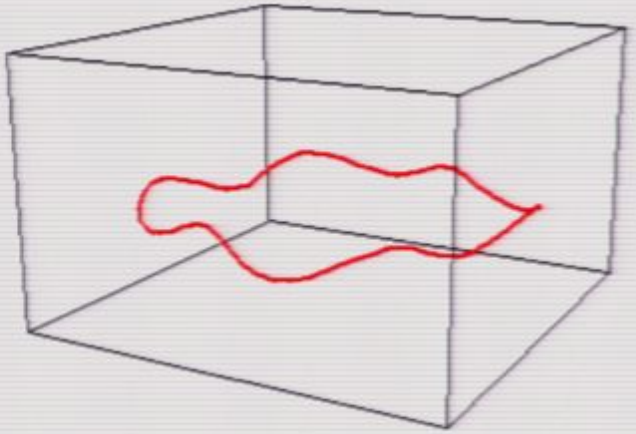


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



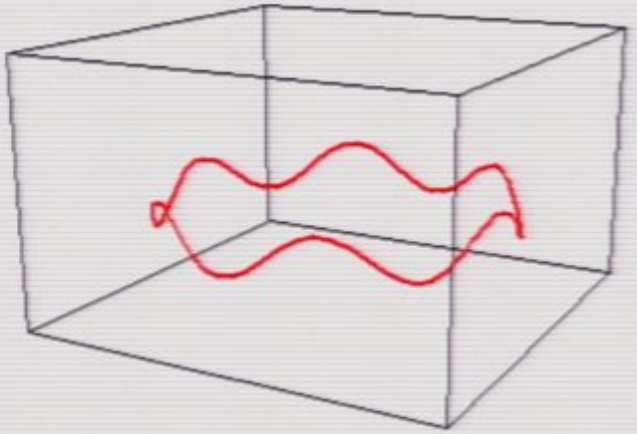


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



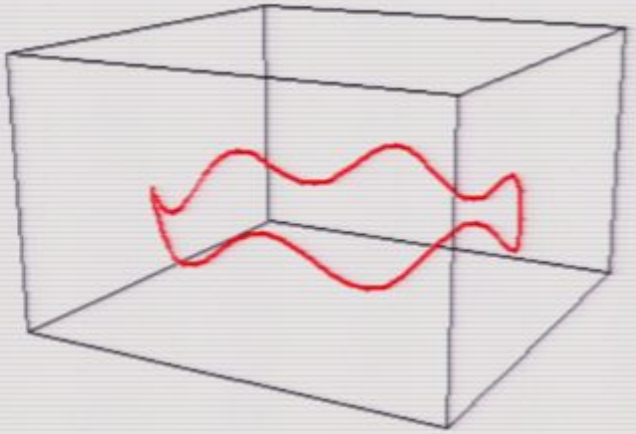


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



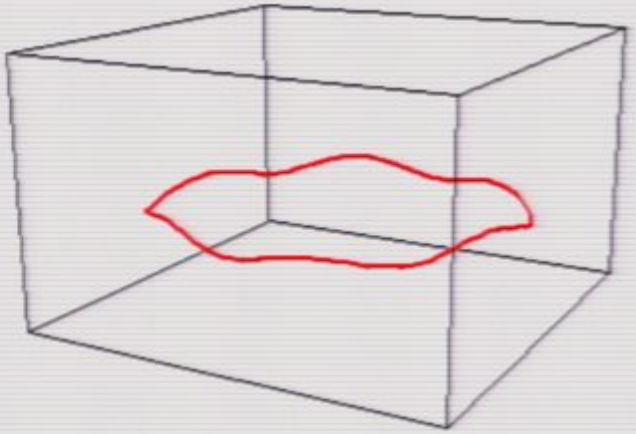


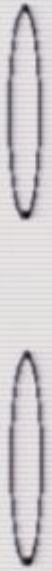
FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings





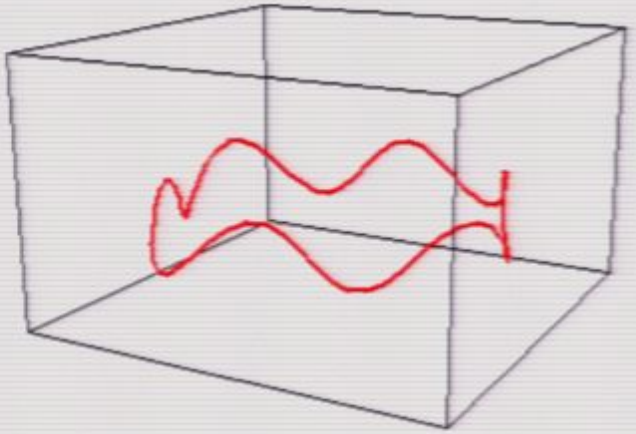


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



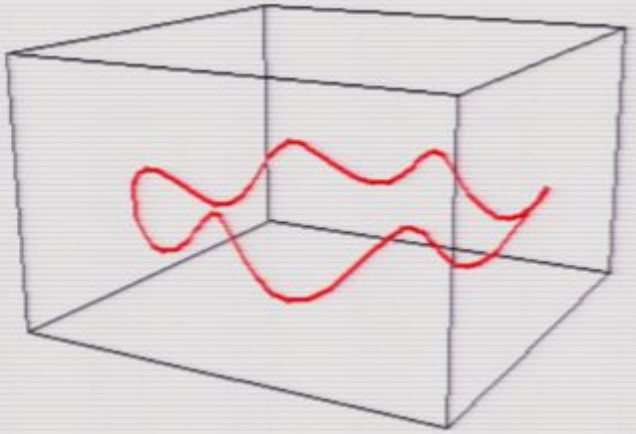


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



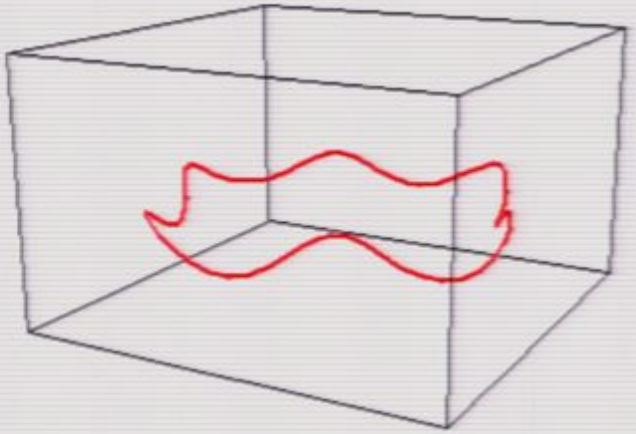


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings



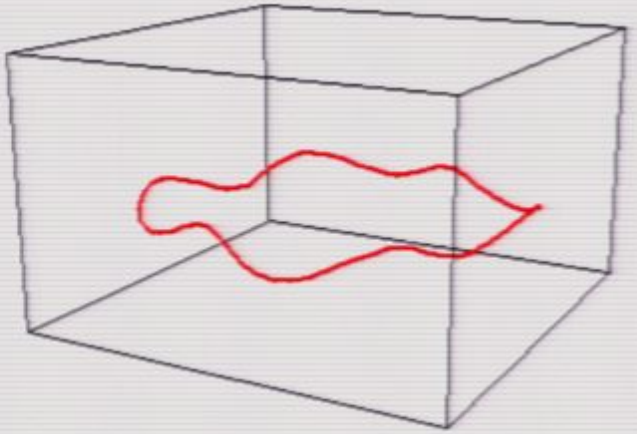


FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

Fundamental strings

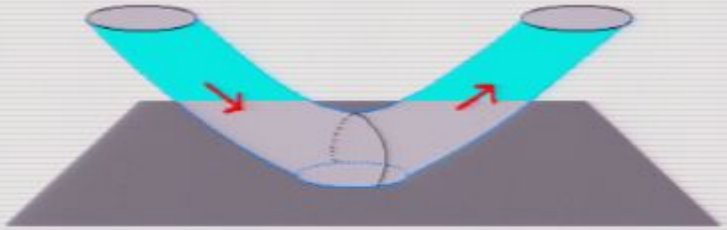




FREE CLOSED STRING
Tension ~ 1

INTERACTION
[generates modifications to GR!!]

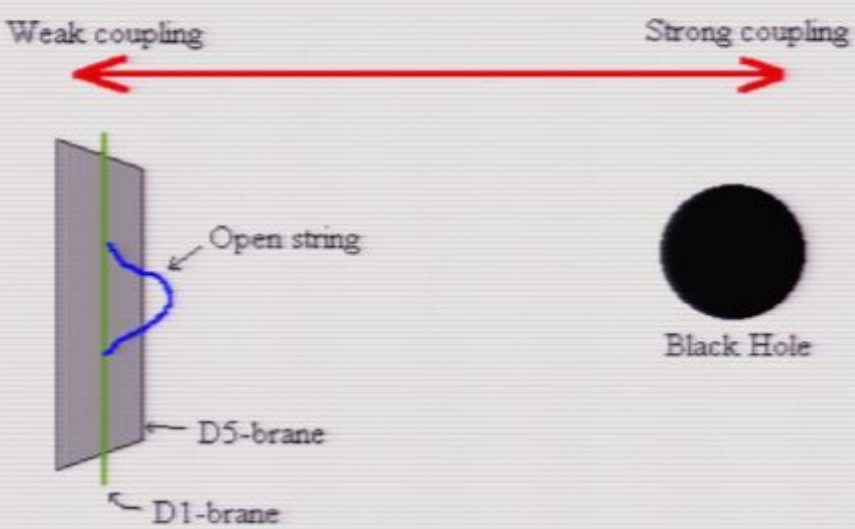
D-branes

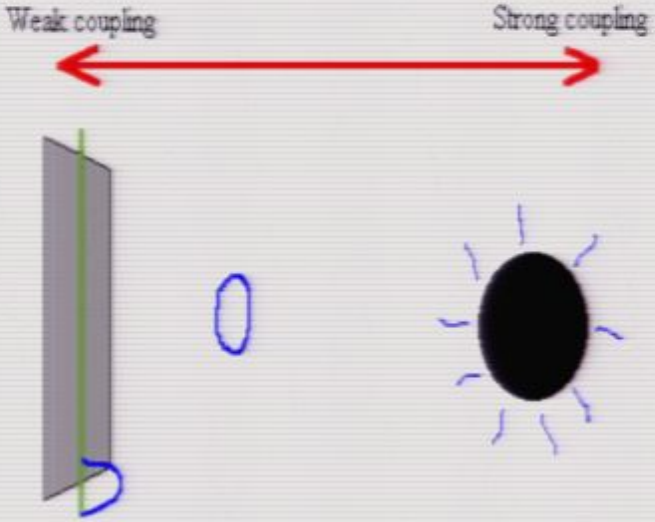


D-brane. Tension ~ $1/g_s$

Closed string absorption by D-brane

Black hole description

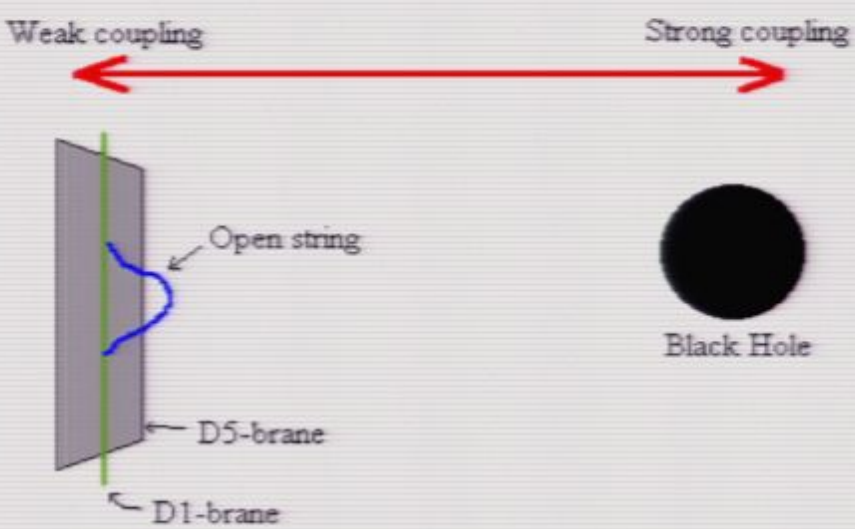


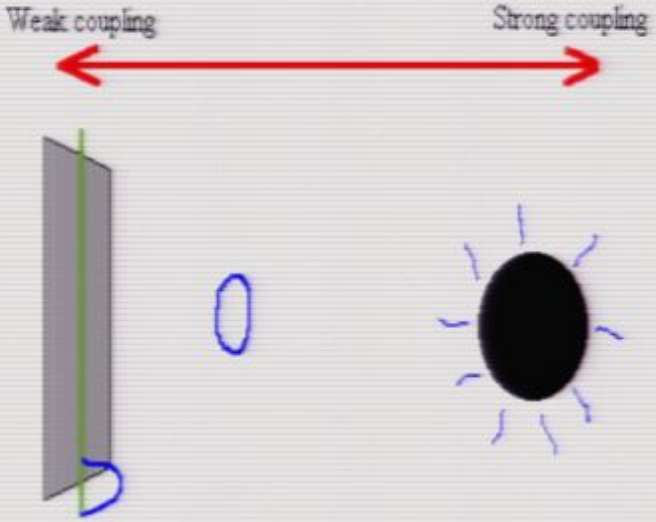


Black hole made by D-branes

Hawking radiation

Black hole description

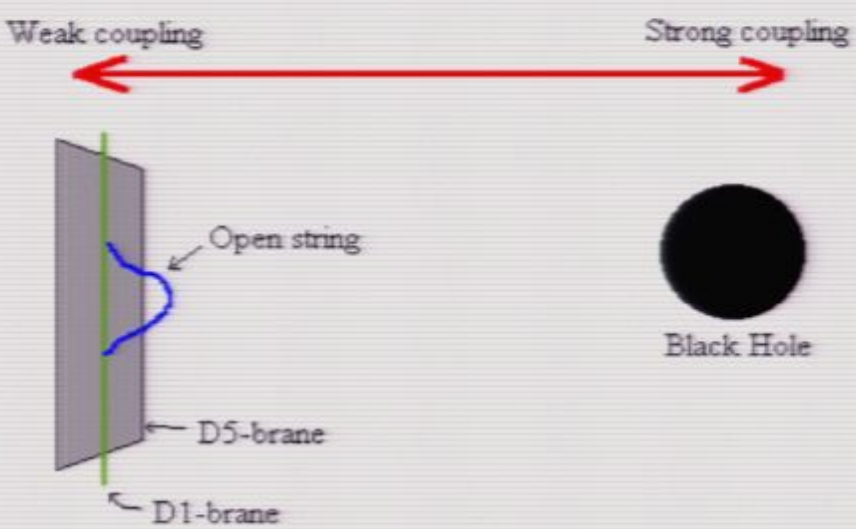


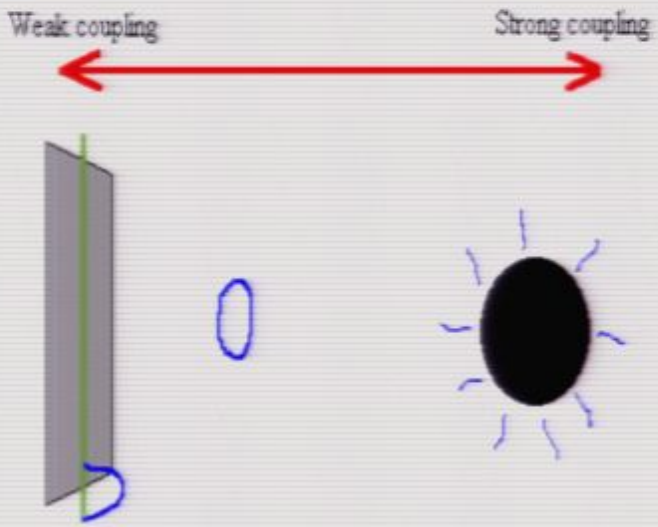


Black hole made by D-branes

Hawking radiation

Black hole description

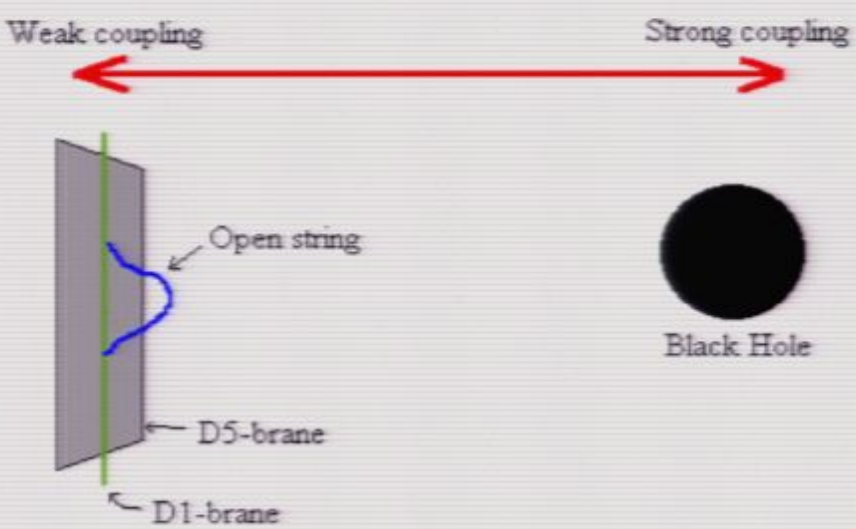


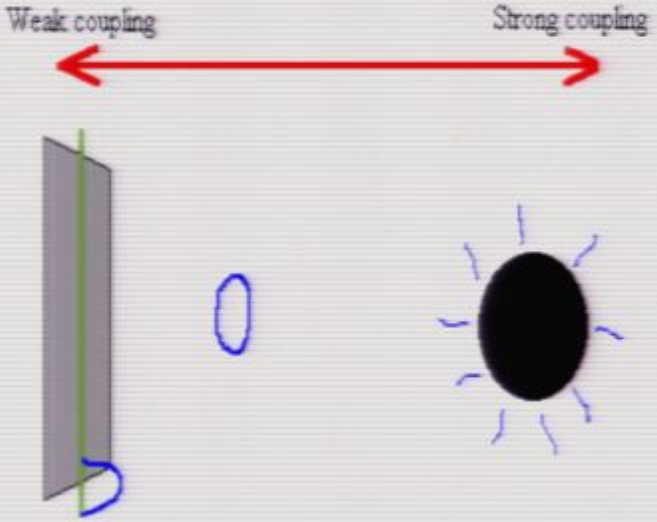


Black hole made by D-branes

Hawking radiation

Black hole description

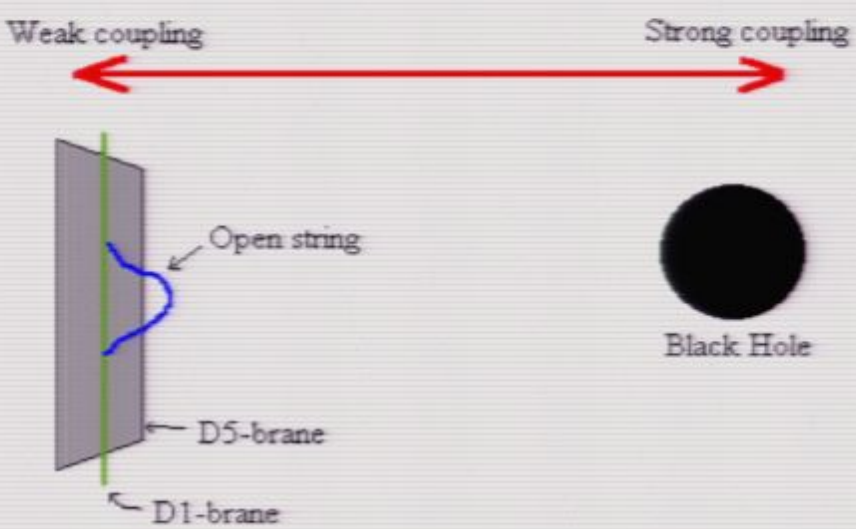


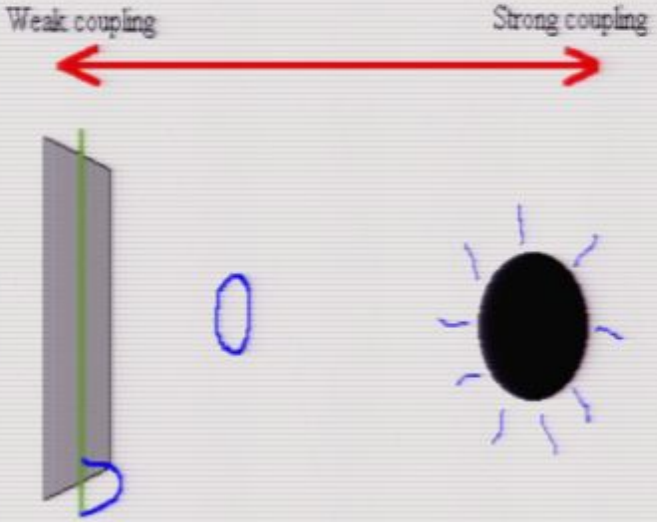


Black hole made by D-branes

Hawking radiation

Black hole description

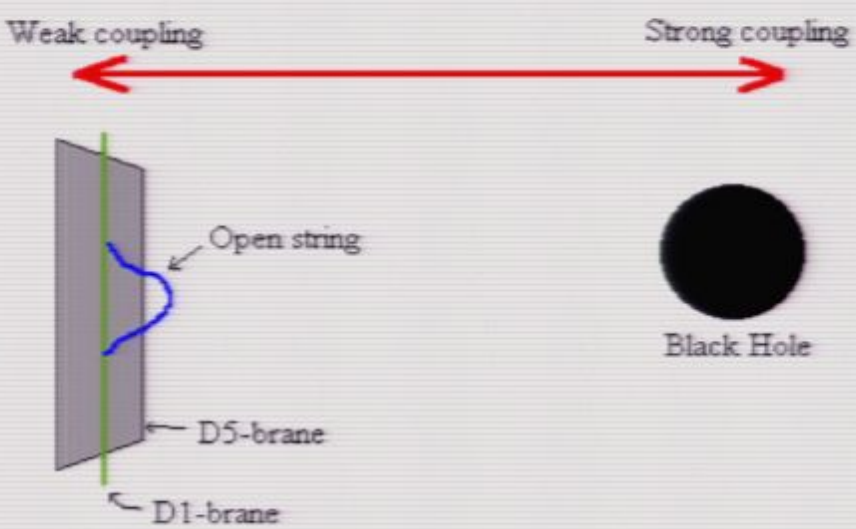


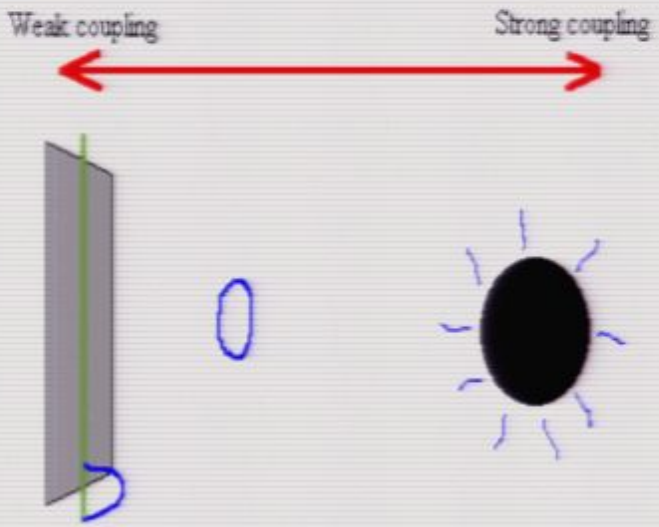


Black hole made by D-branes

Hawking radiation

Black hole description

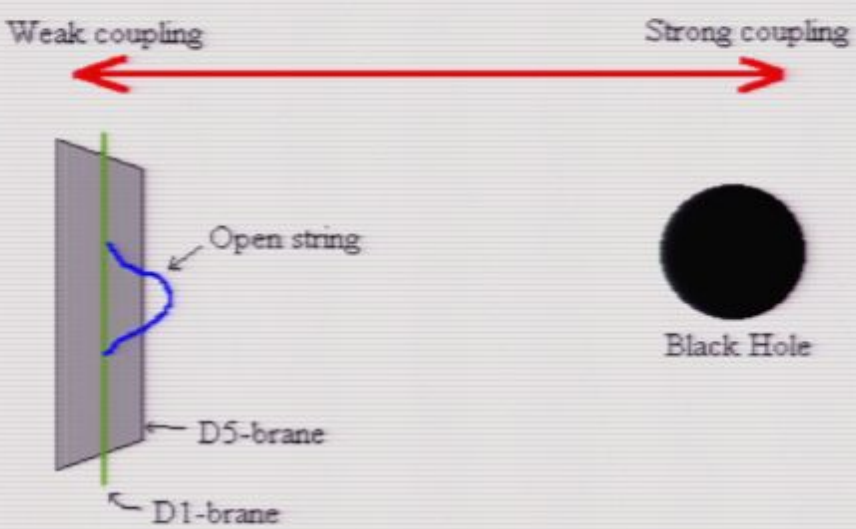


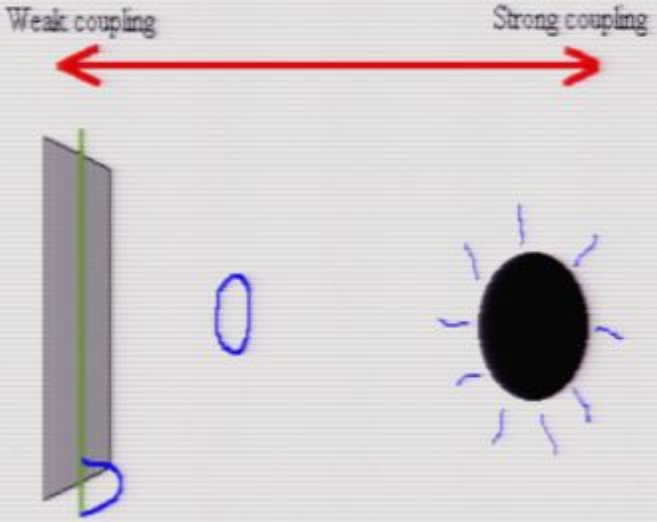


Black hole made by D-branes

Hawking radiation

Black hole description

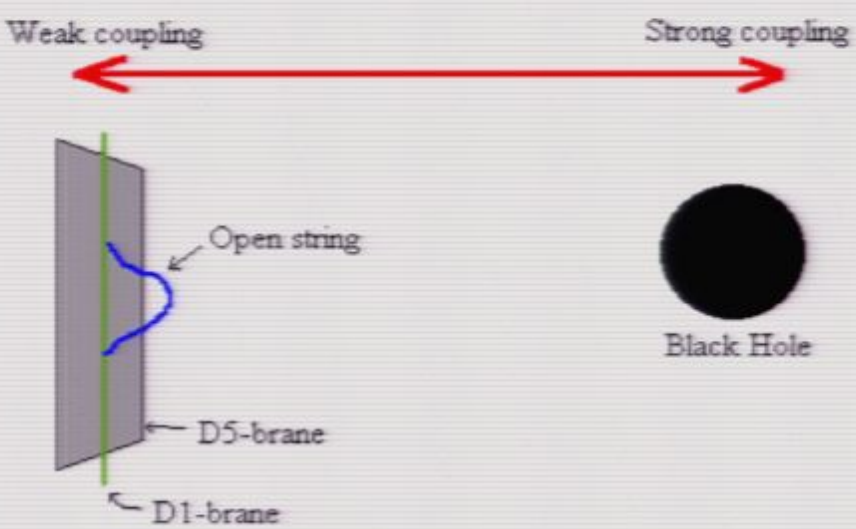


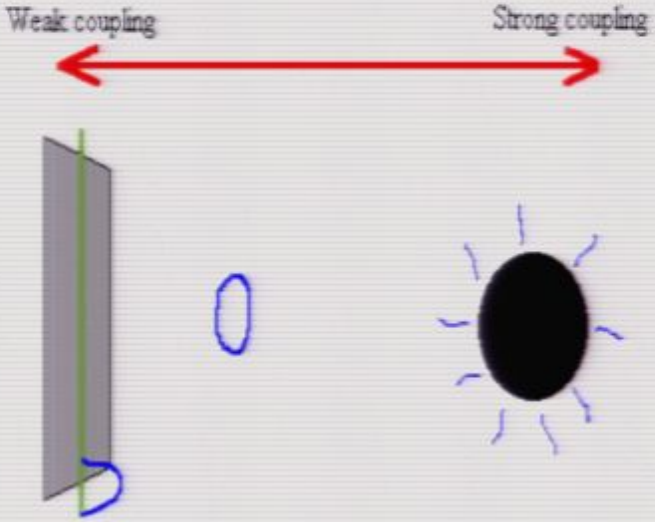


Black hole made by D-branes

Hawking radiation

Black hole description

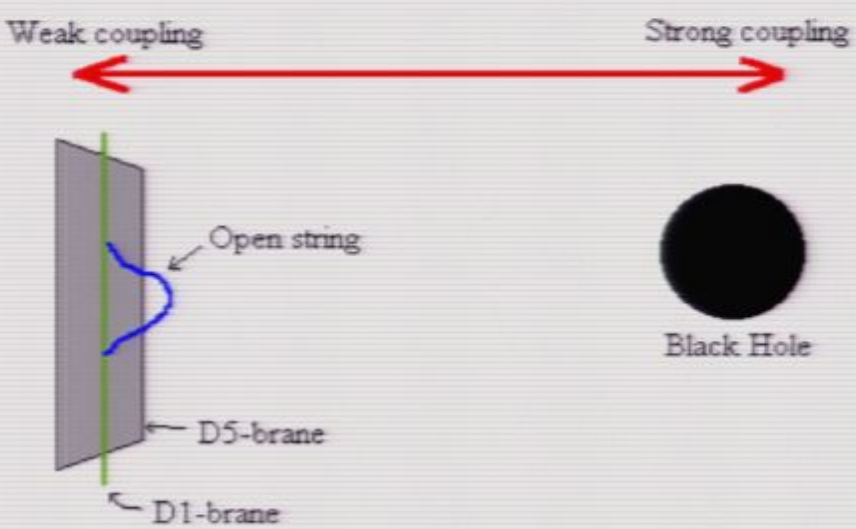


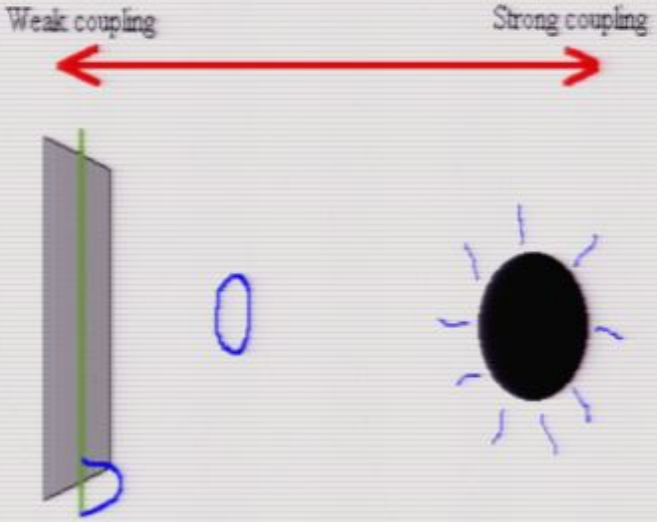


Black hole made by D-branes

Hawking radiation

Black hole description

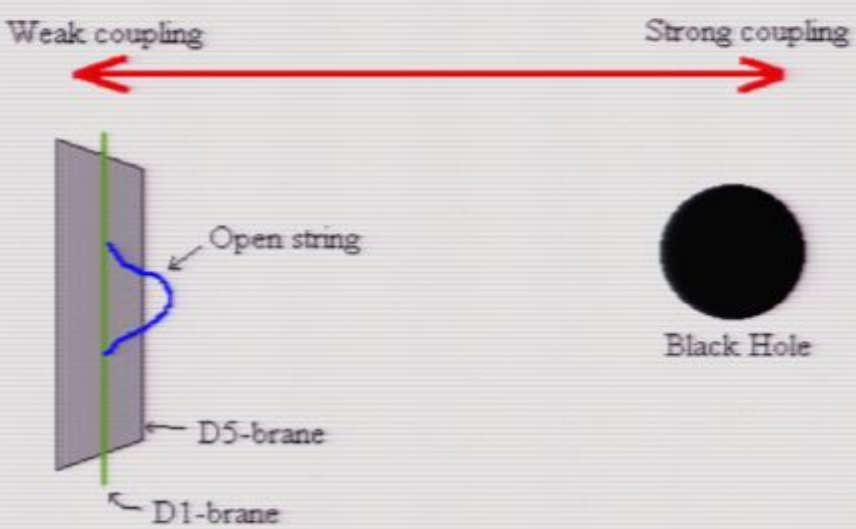


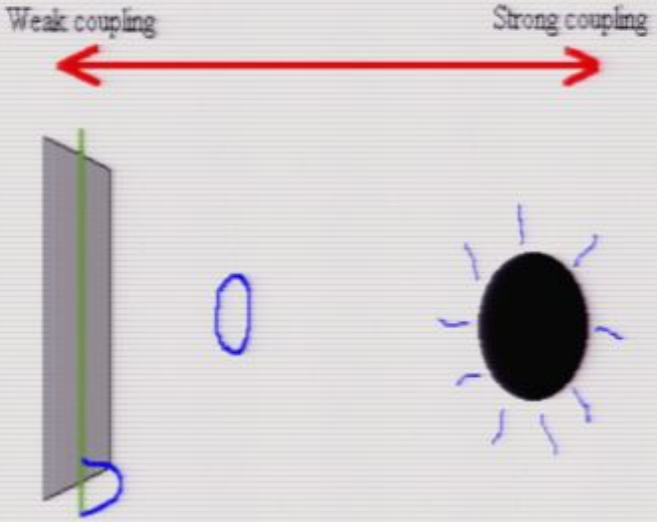


Black hole made by D-branes

Hawking radiation

Black hole description

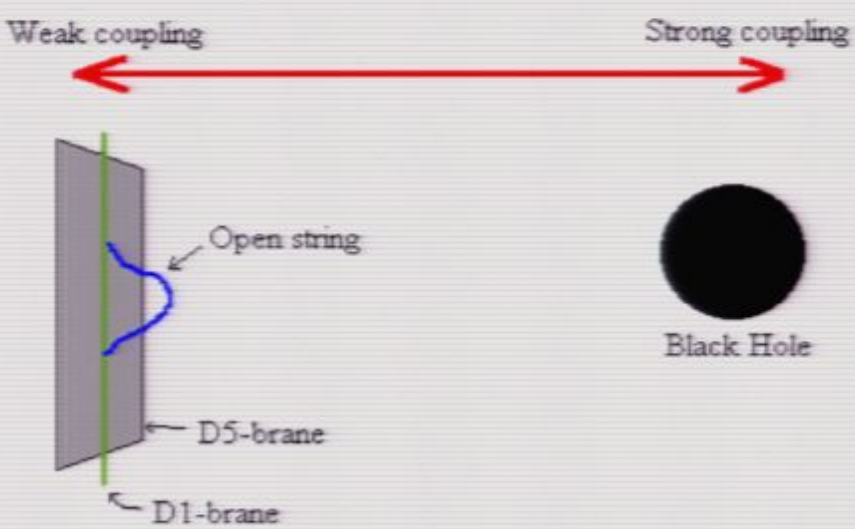


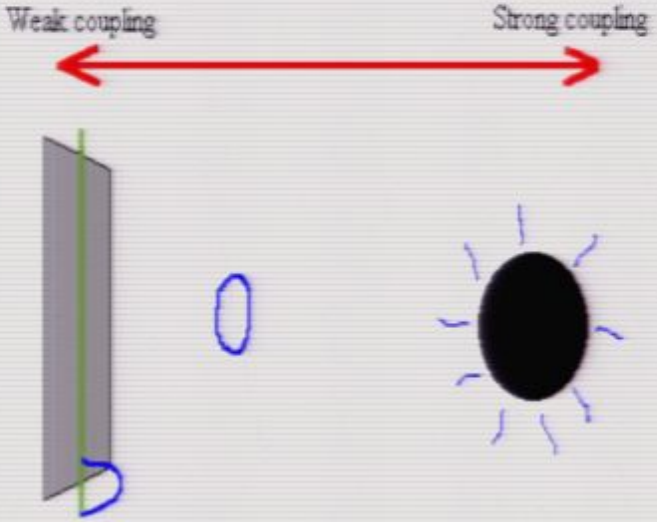


Black hole made by D-branes

Hawking radiation

Black hole description

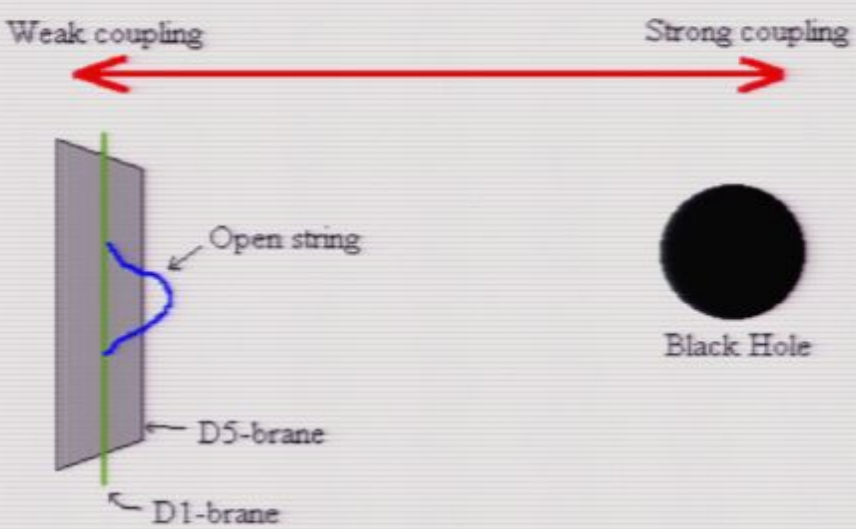


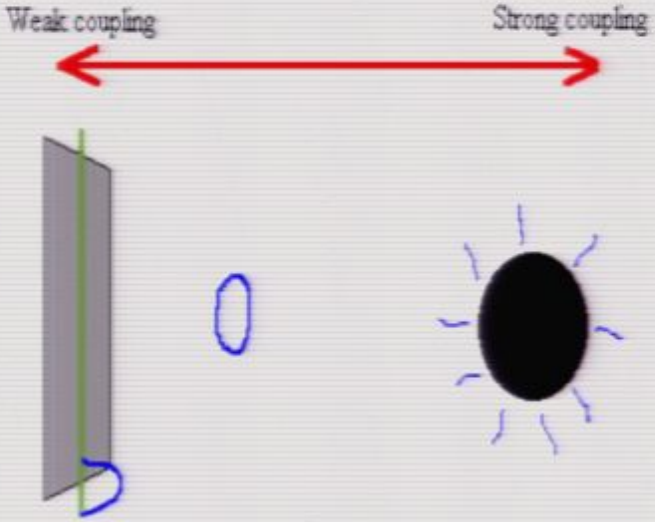


Black hole made by D-branes

Hawking radiation

Black hole description

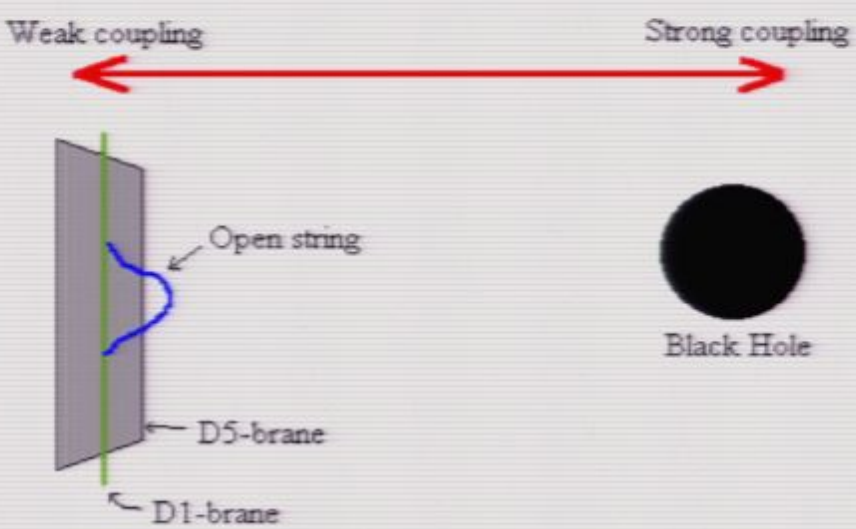


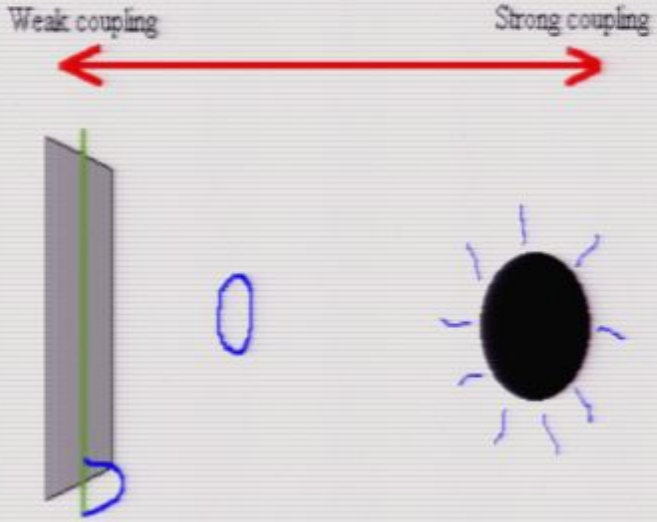


Black hole made by D-branes

Hawking radiation

Black hole description

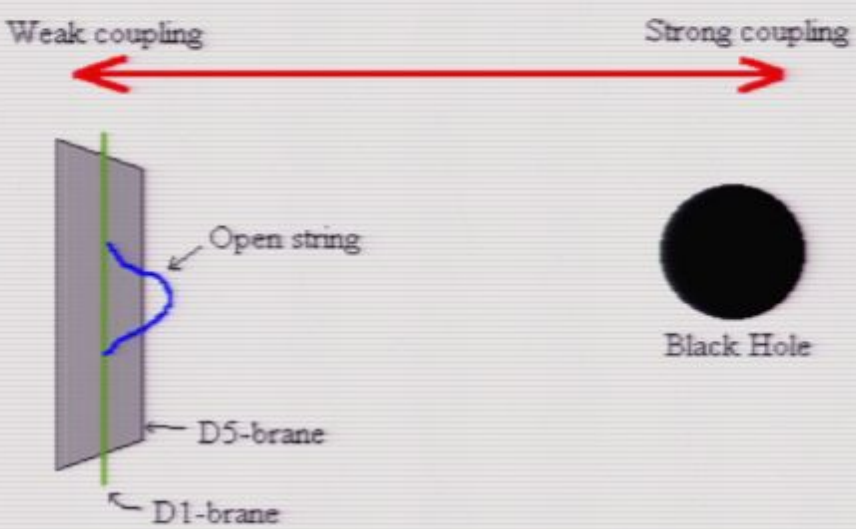


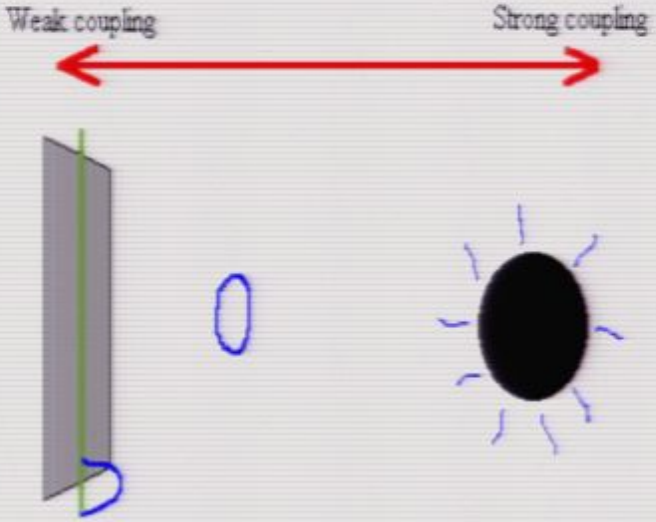


Black hole made by D-branes

Hawking radiation

Black hole description

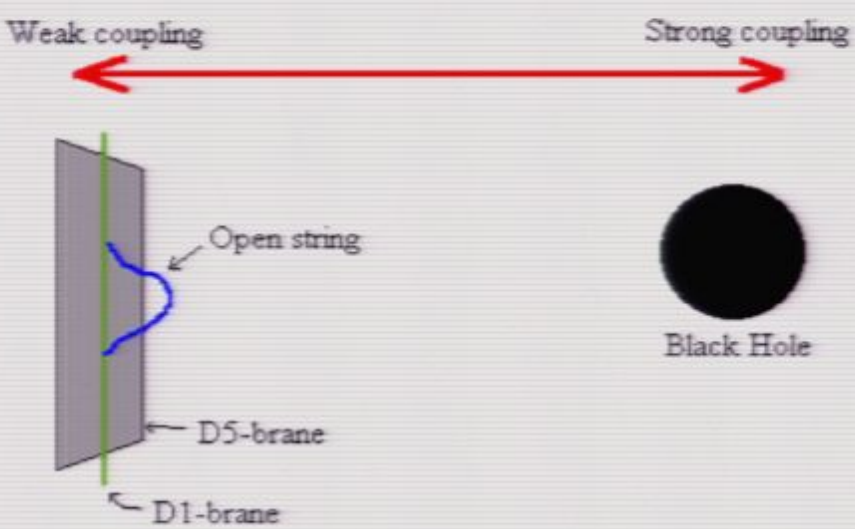


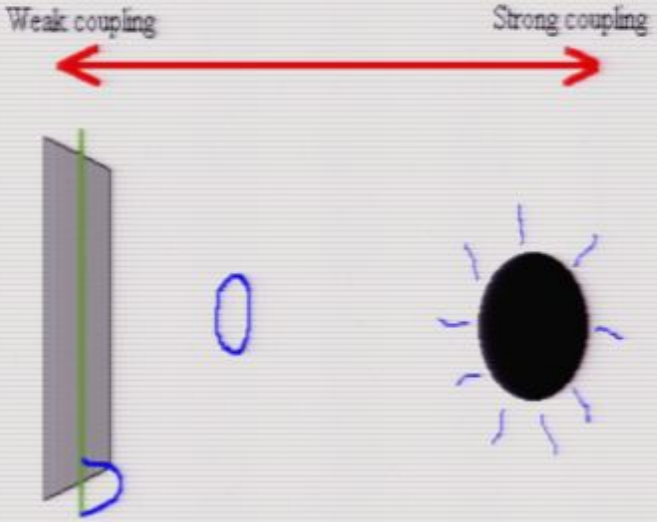


Black hole made by D-branes

Hawking radiation

Black hole description

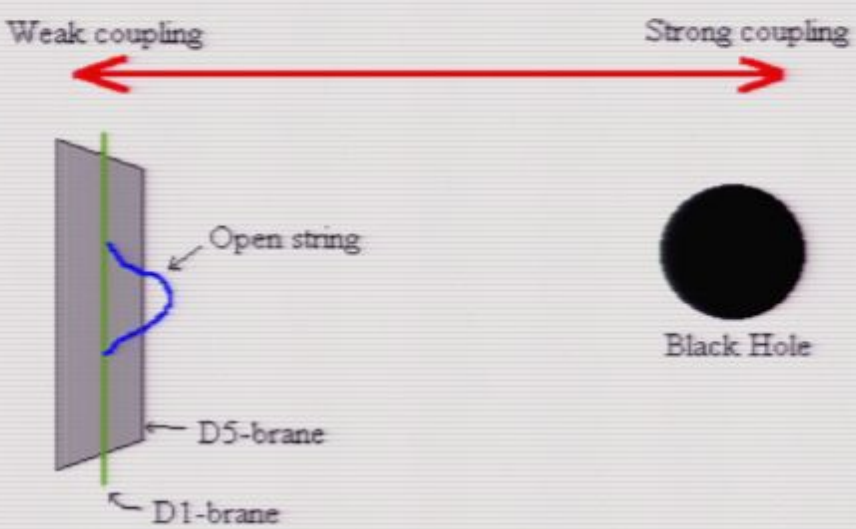


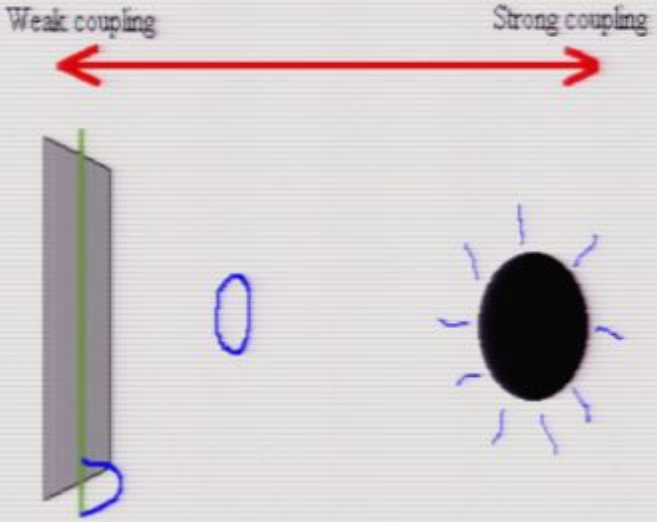


Black hole made by D-branes

Hawking radiation

Black hole description

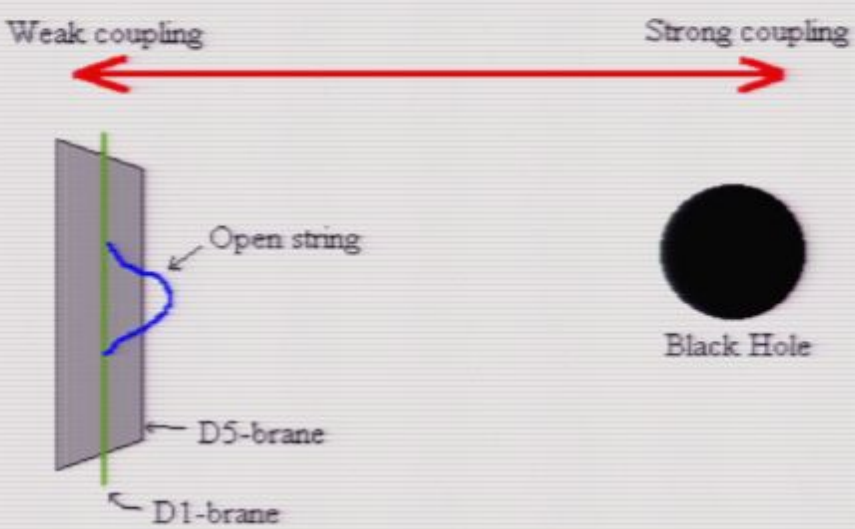


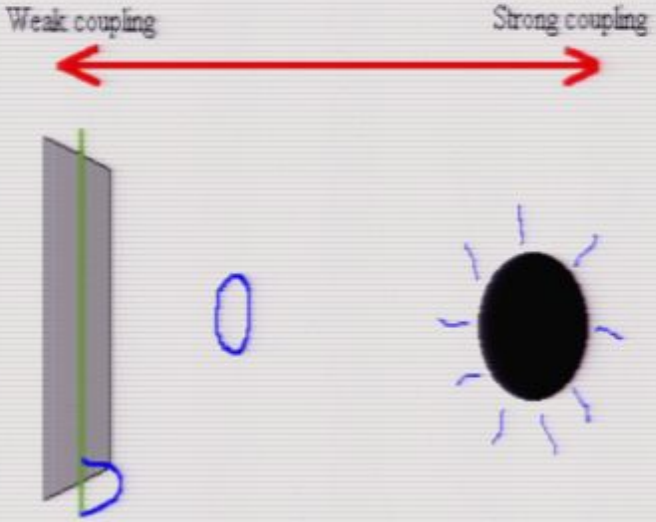


Black hole made by D-branes

Hawking radiation

Black hole description

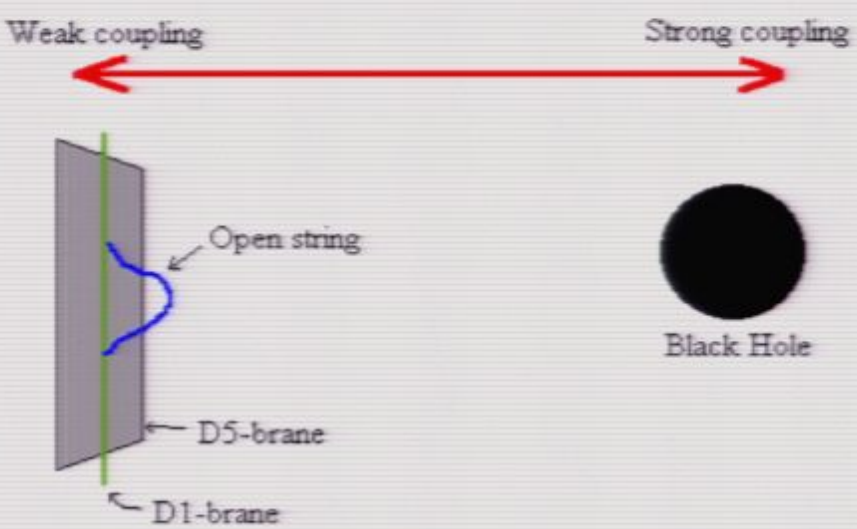


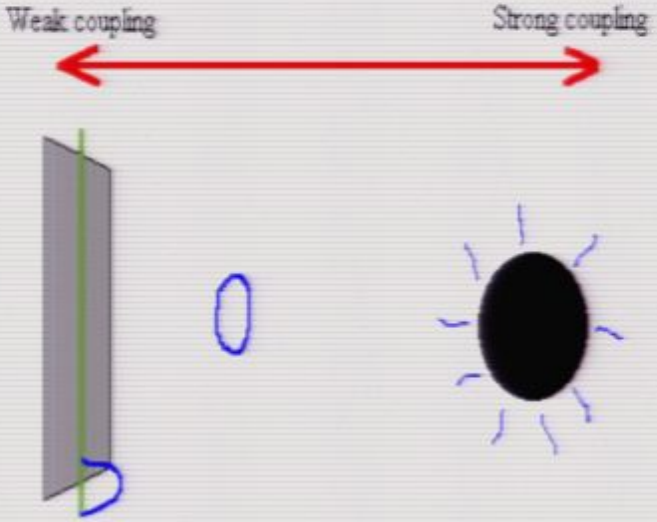


Black hole made by D-branes

Hawking radiation

Black hole description

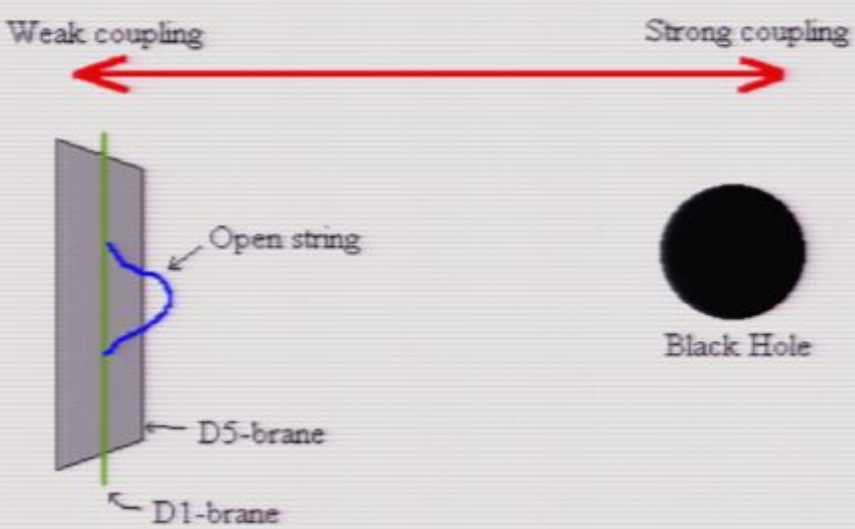


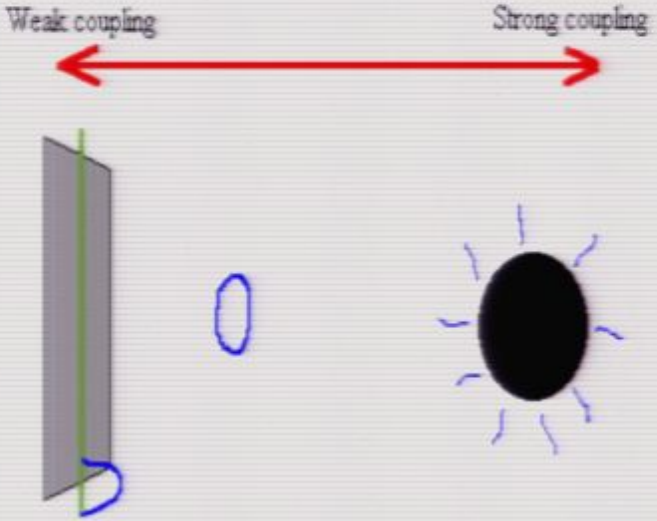


Black hole made by D-branes

Hawking radiation

Black hole description

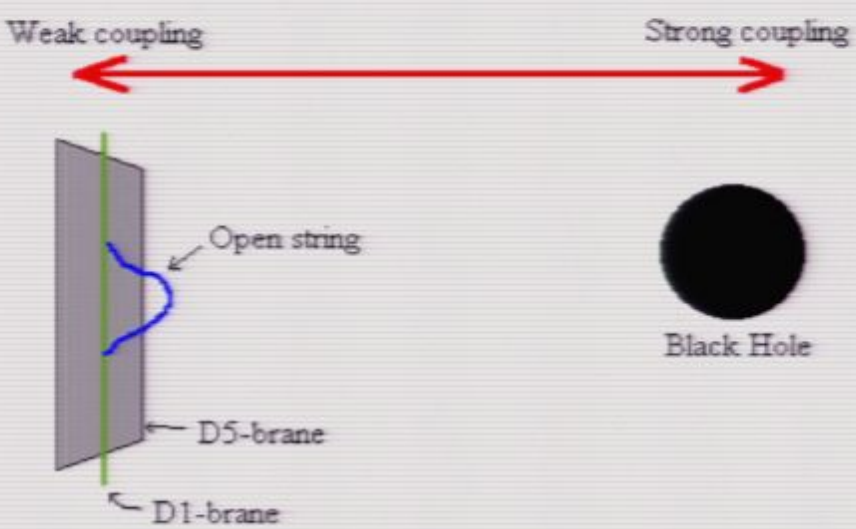


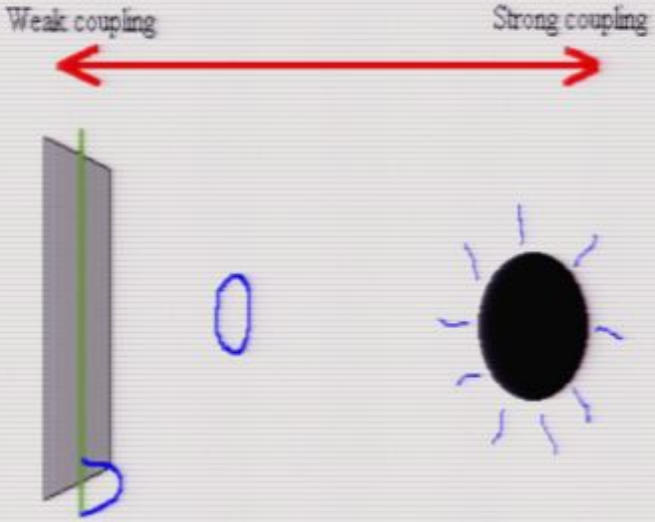


Black hole made by D-branes

Hawking radiation

Black hole description

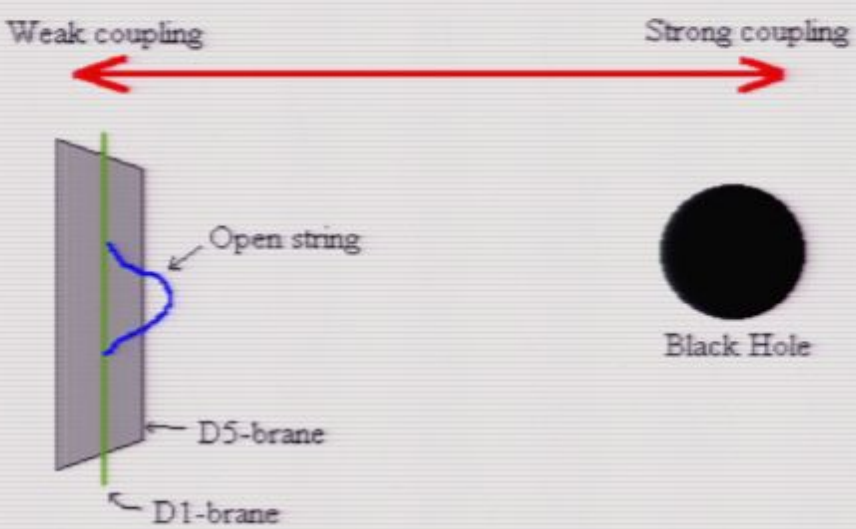


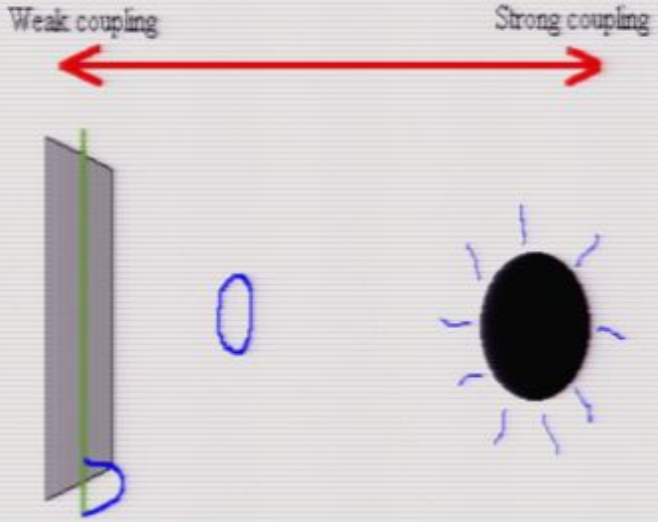


Black hole made by D-branes

Hawking radiation

Black hole description

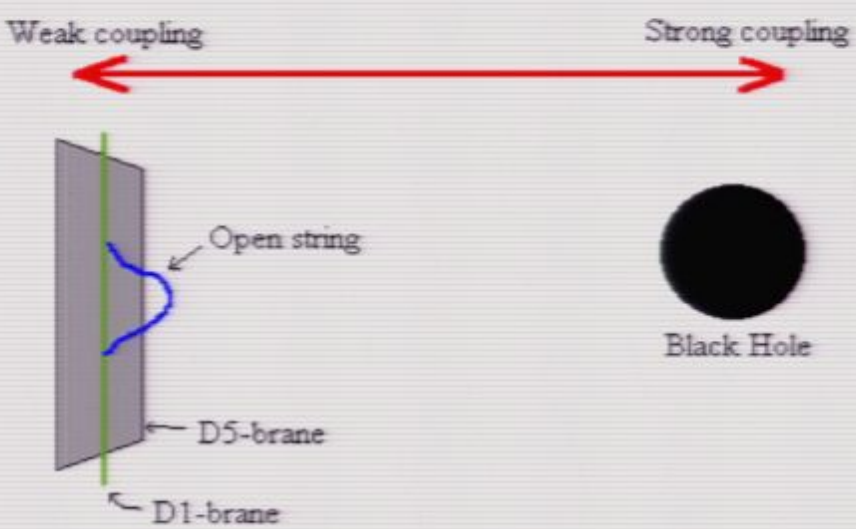


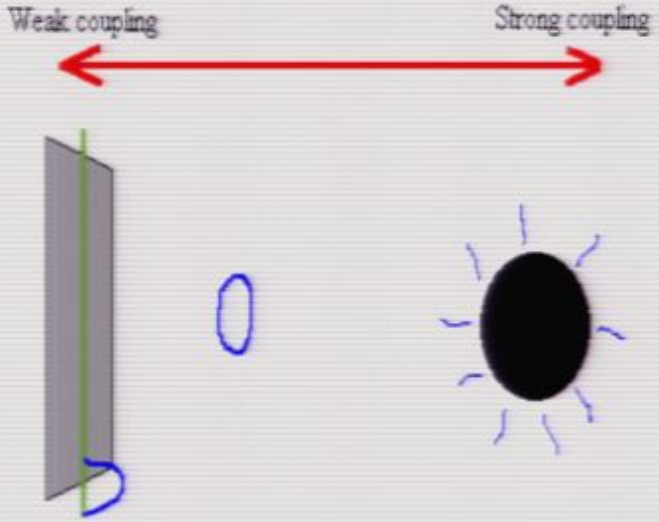


Black hole made by D-branes

Hawking radiation

Black hole description

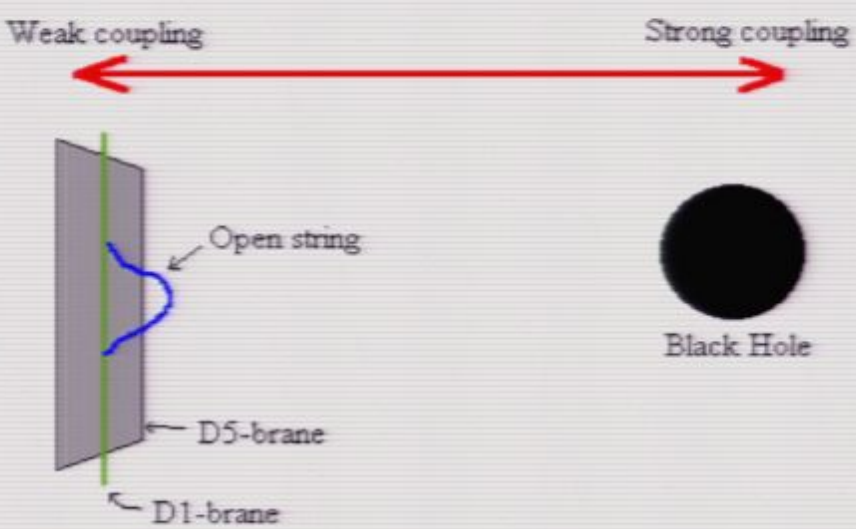


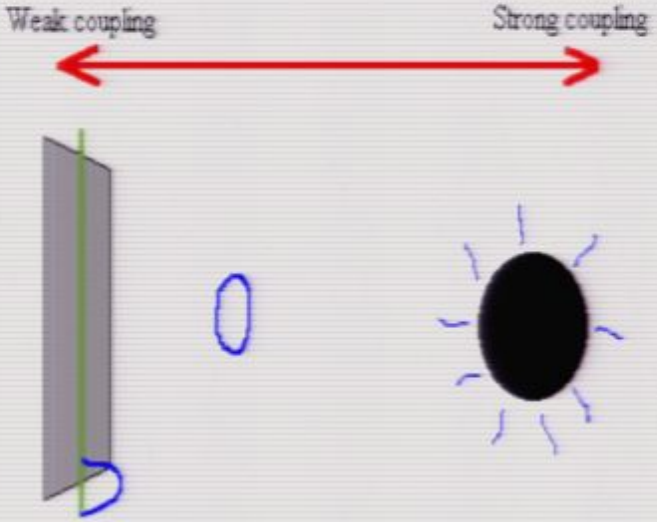


Black hole made by D-branes

Hawking radiation

Black hole description

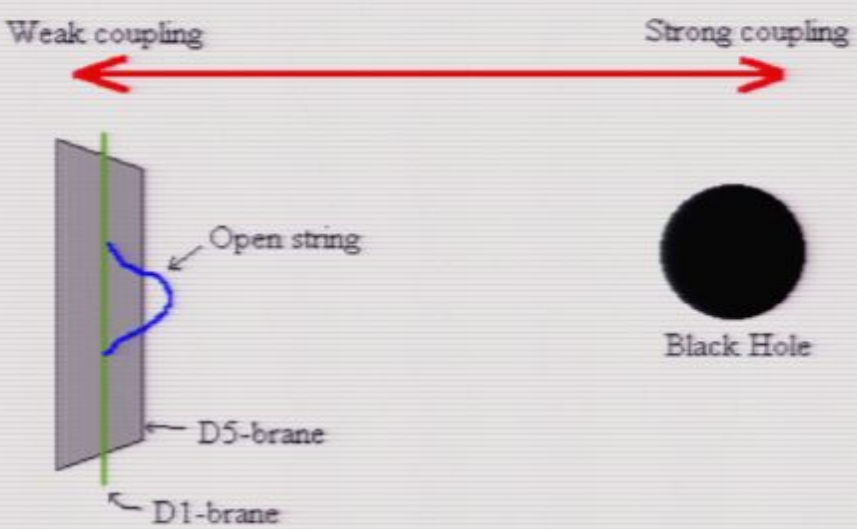


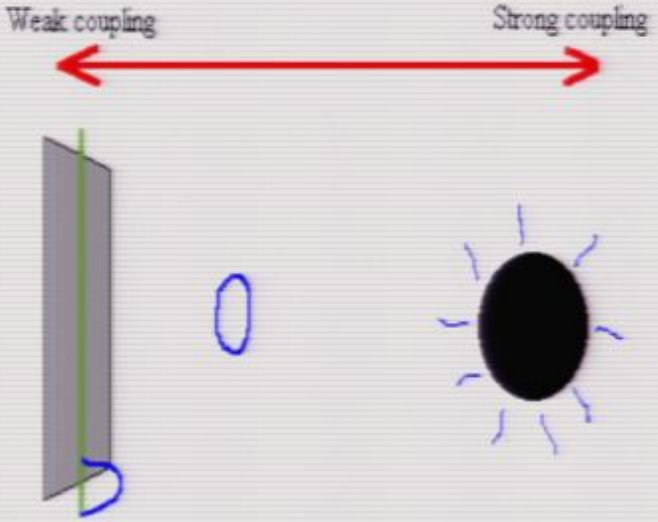


Black hole made by D-branes

Hawking radiation

Black hole description

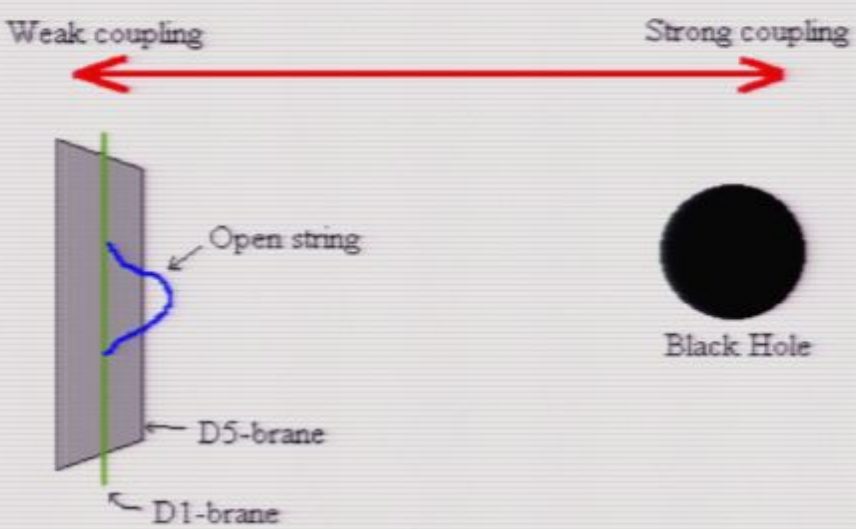


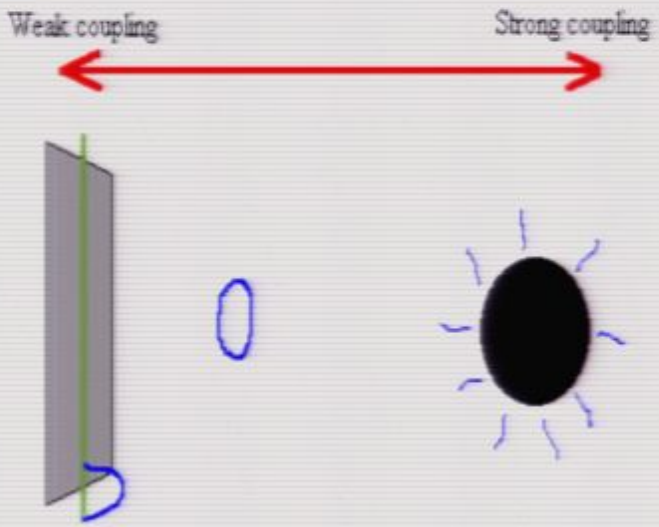


Black hole made by D-branes

Hawking radiation

Black hole description

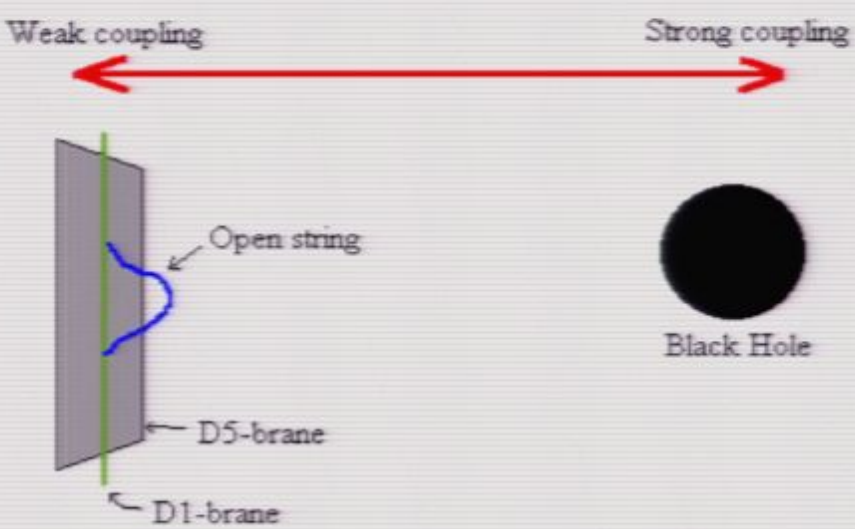


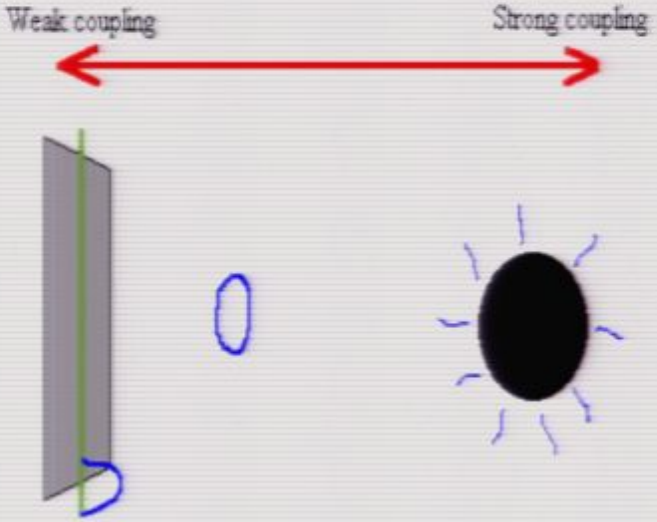


Black hole made by D-branes

Hawking radiation

Black hole description

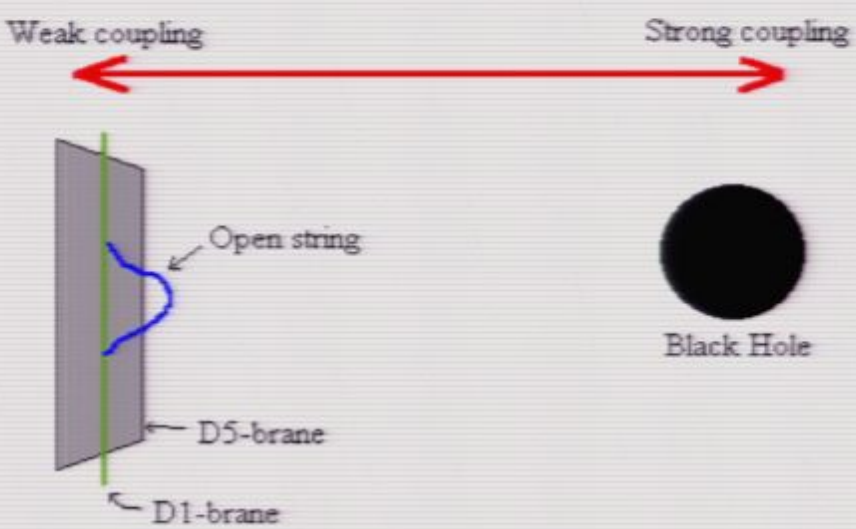


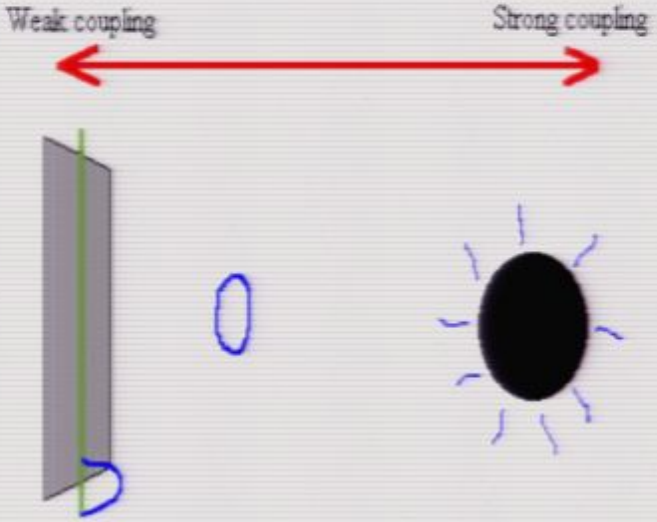


Black hole made by D-branes

Hawking radiation

Black hole description

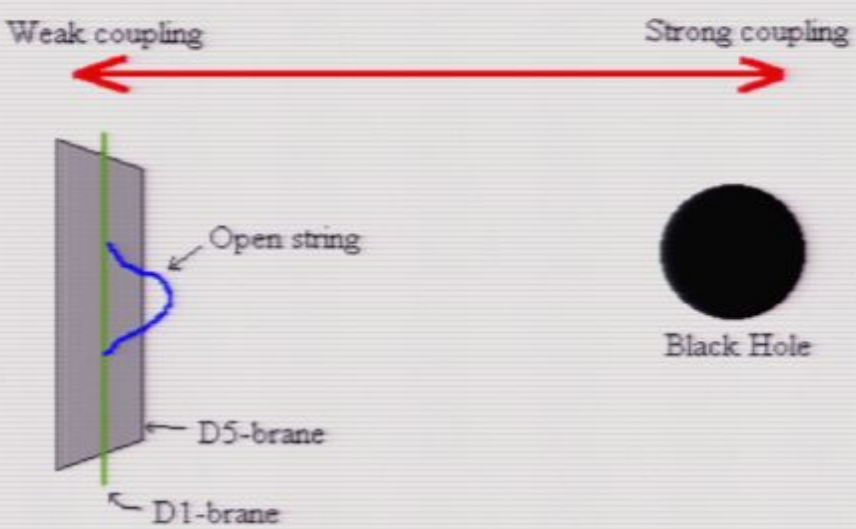


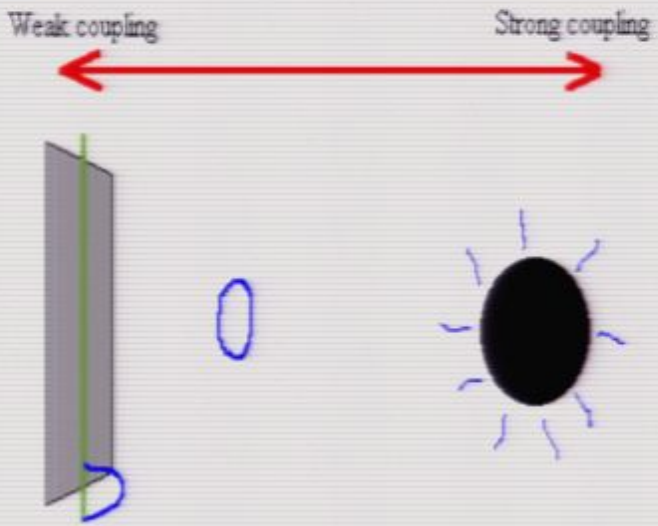


Black hole made by D-branes

Hawking radiation

Black hole description

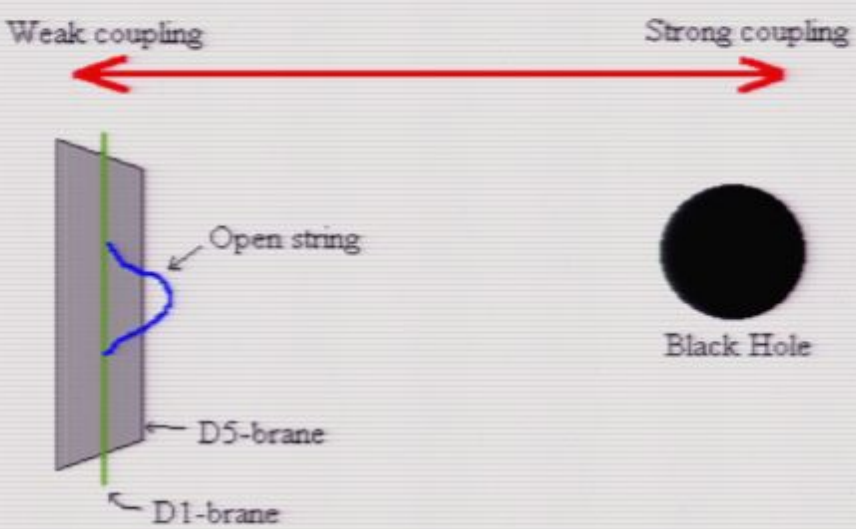


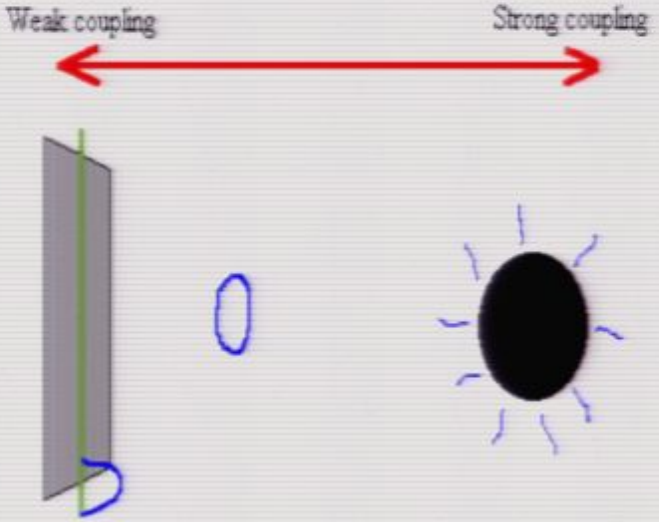


Black hole made by D-branes

Hawking radiation

Black hole description

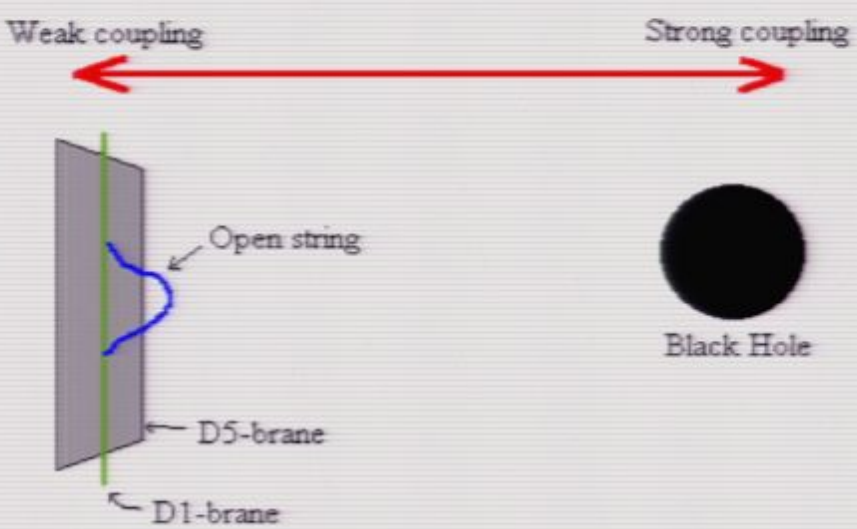


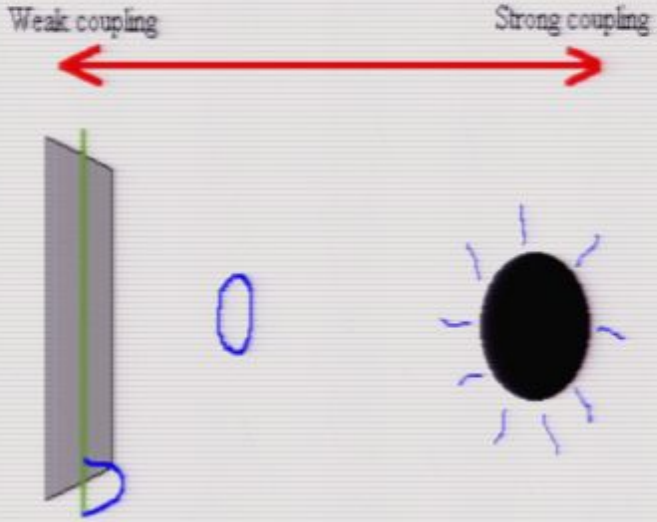


Black hole made by D-branes

Hawking radiation

Black hole description

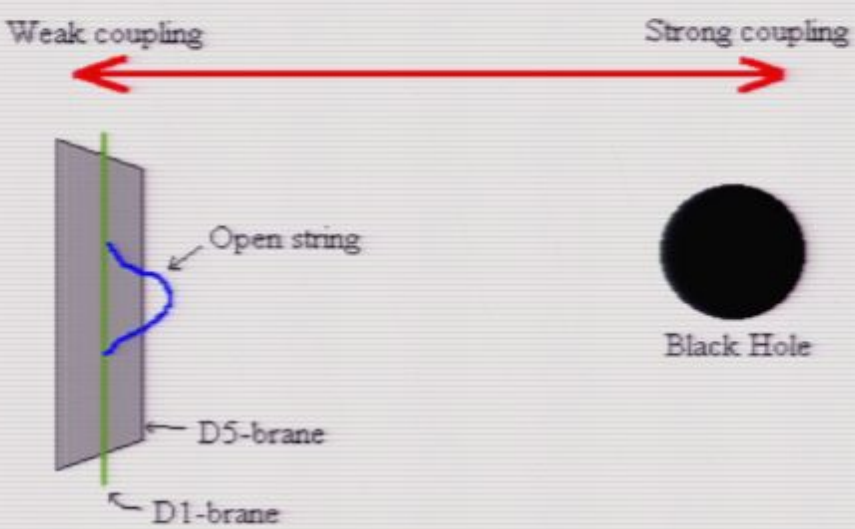


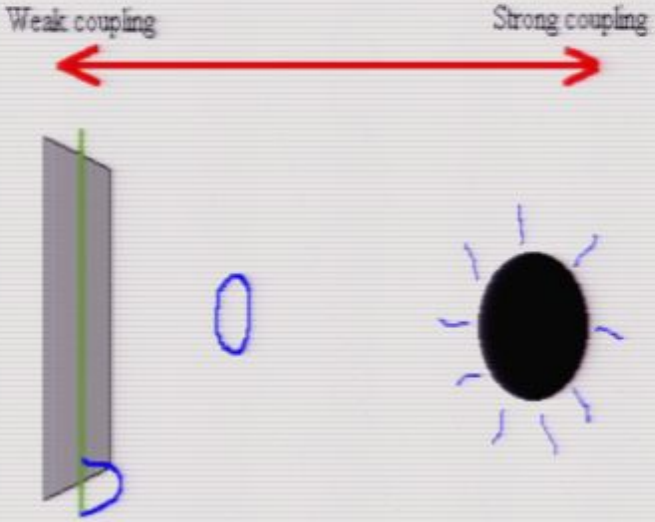


Black hole made by D-branes

Hawking radiation

Black hole description

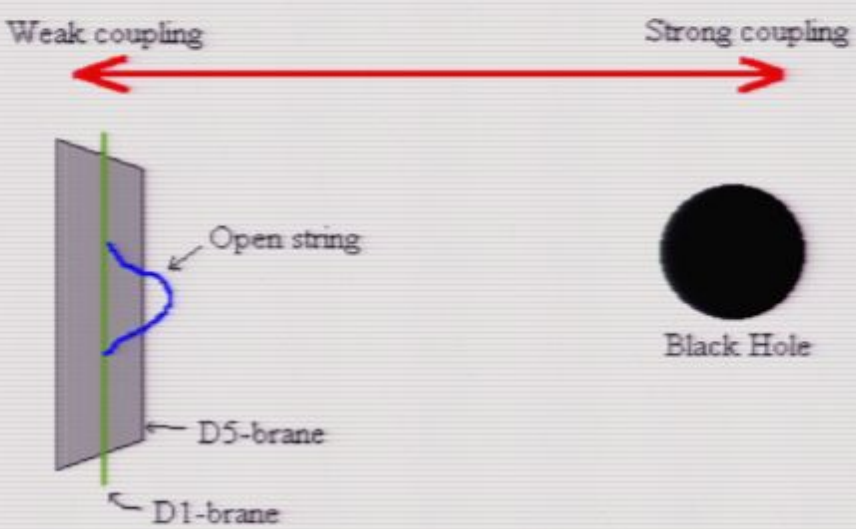


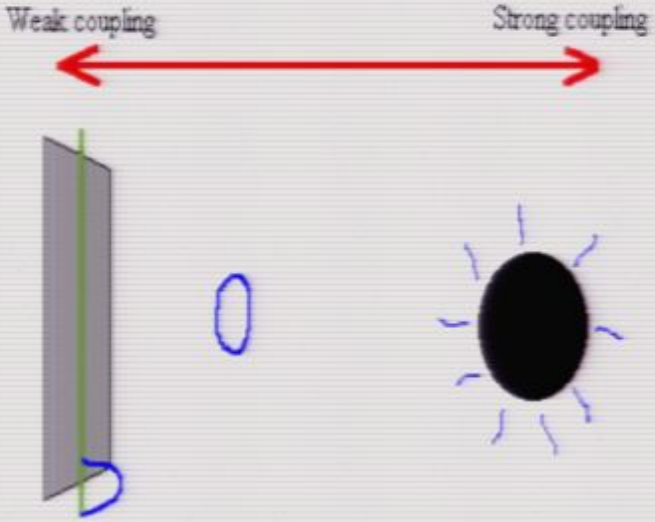


Black hole made by D-branes

Hawking radiation

Black hole description

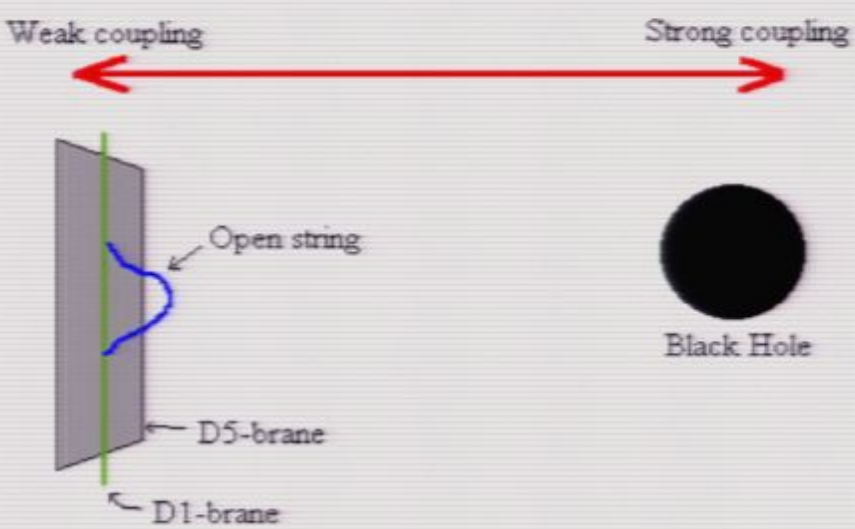


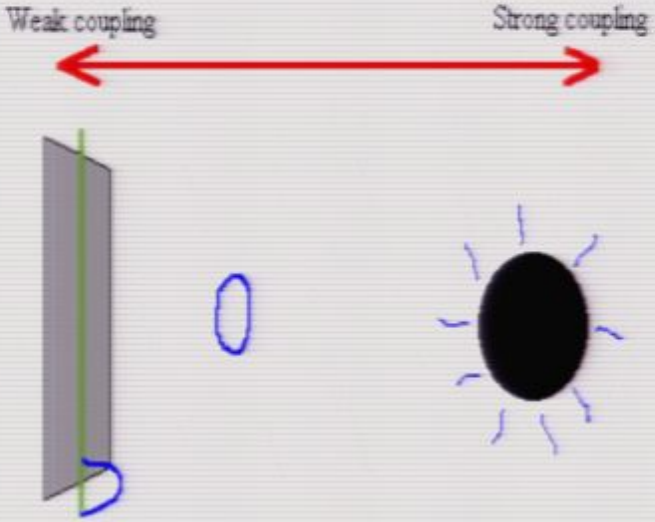


Black hole made by D-branes

Hawking radiation

Black hole description

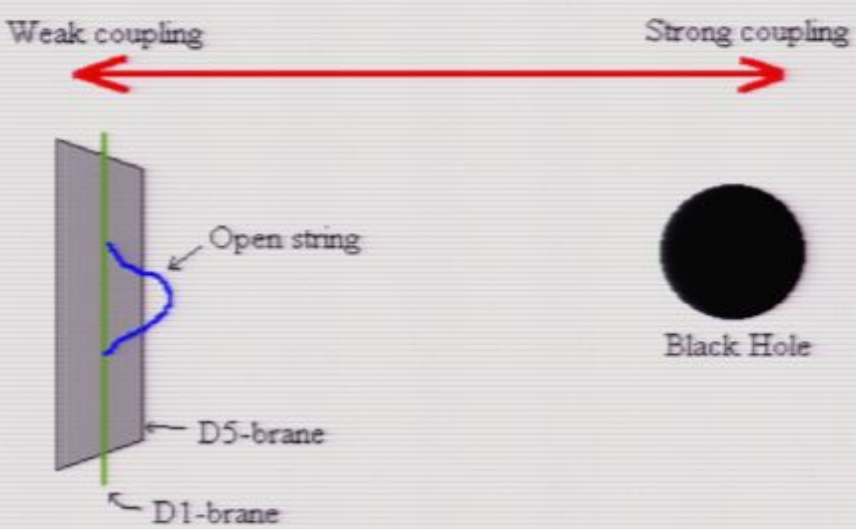


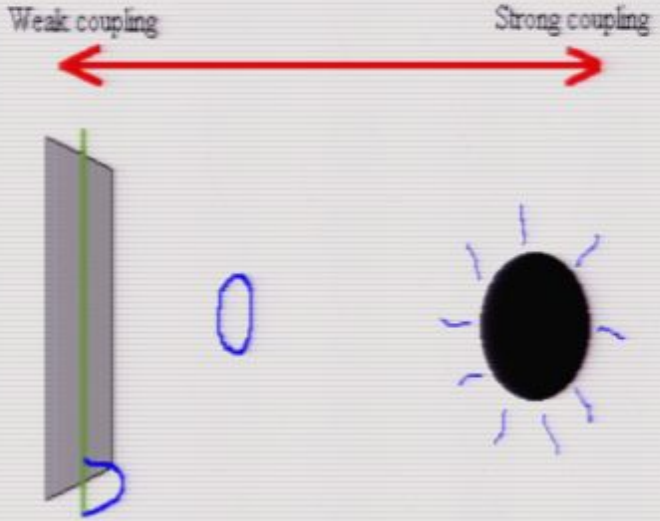


Black hole made by D-branes

Hawking radiation

Black hole description

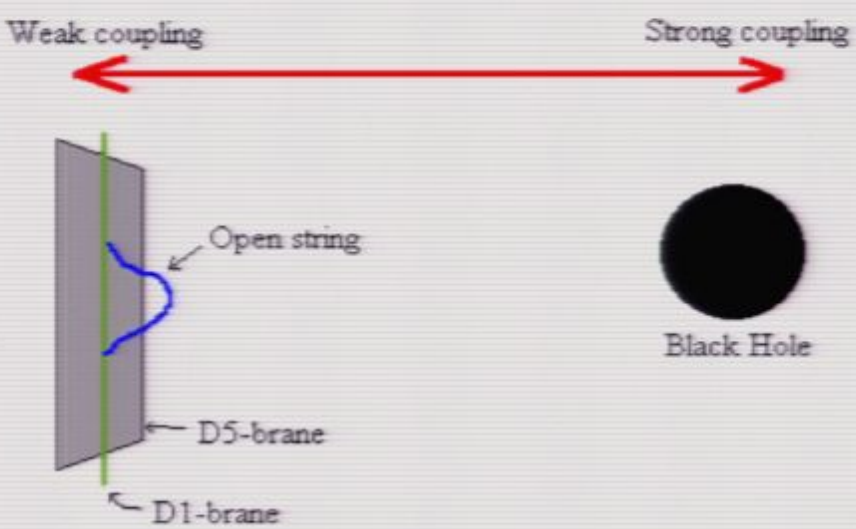


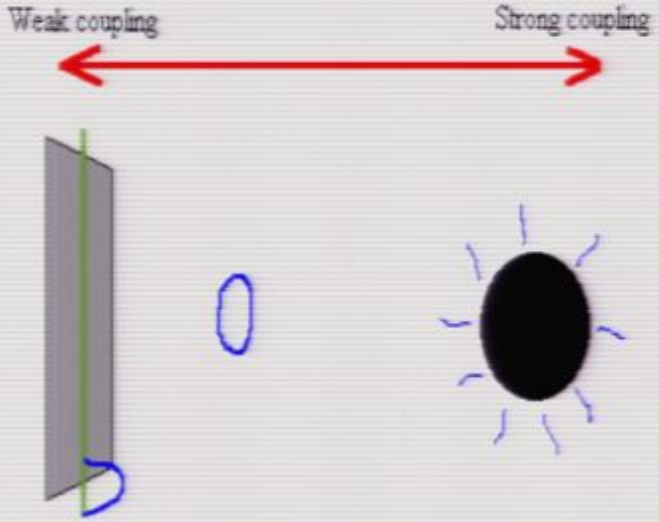


Black hole made by D-branes

Hawking radiation

Black hole description

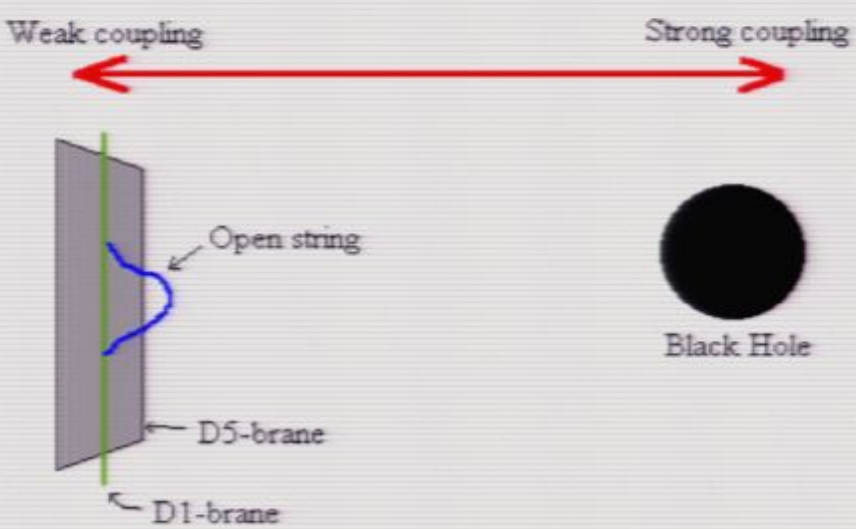


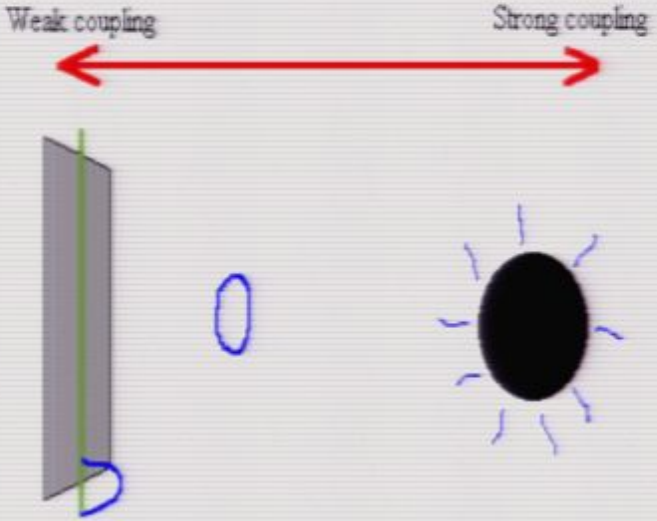


Black hole made by D-branes

Hawking radiation

Black hole description

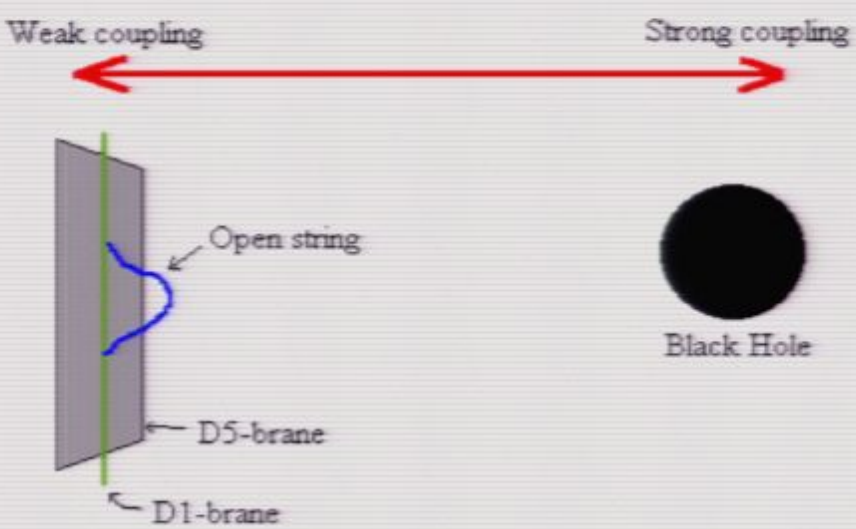


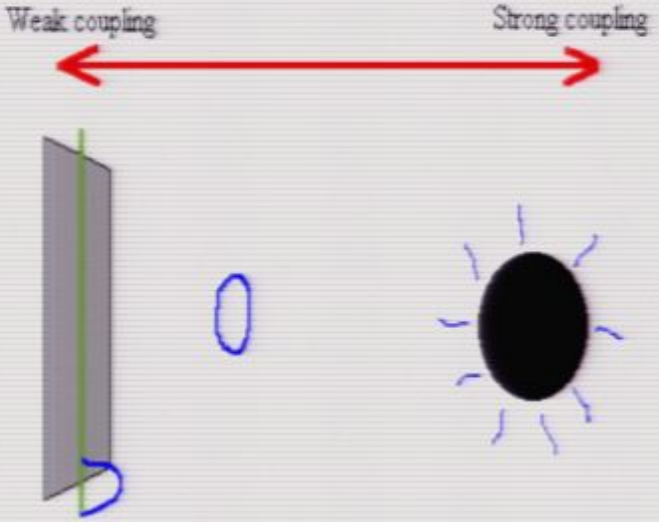


Black hole made by D-branes

Hawking radiation

Black hole description

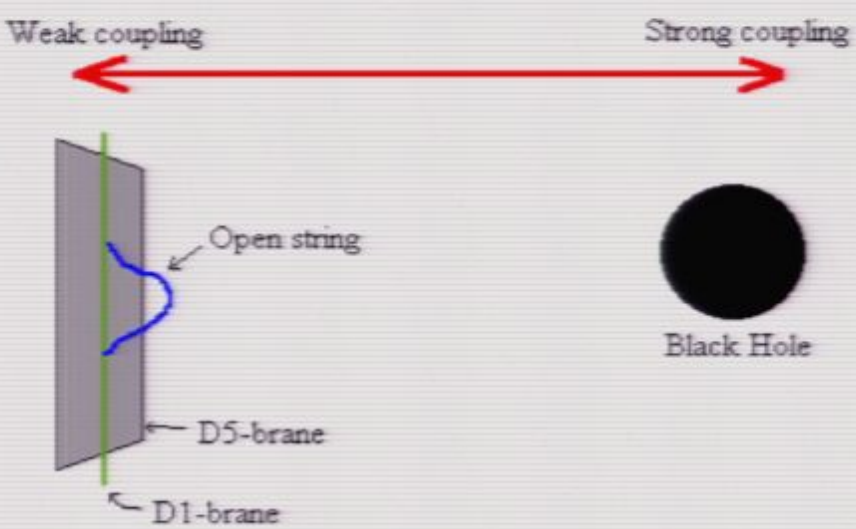


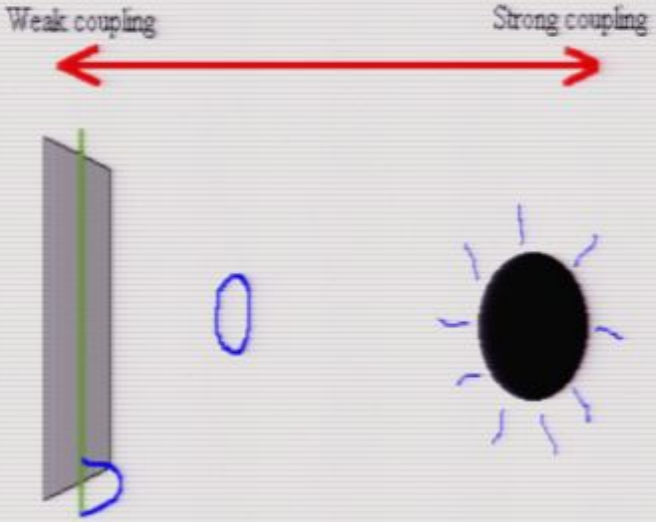


Black hole made by D-branes

Hawking radiation

Black hole description

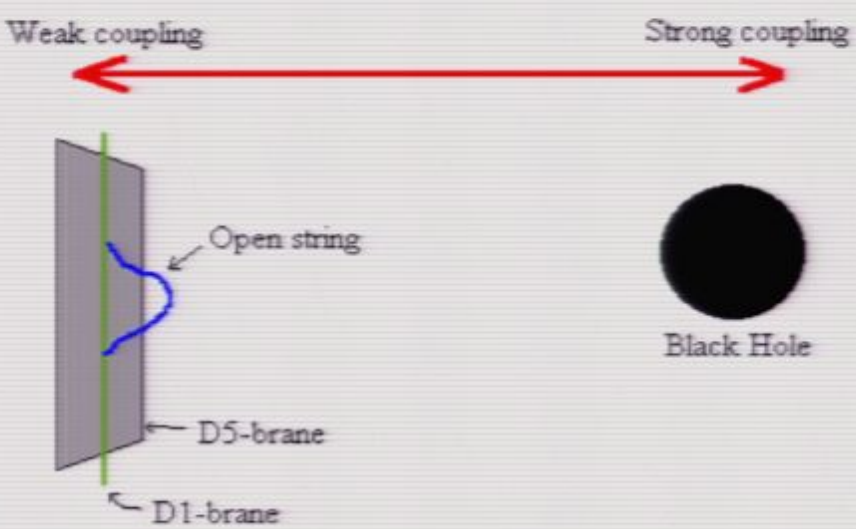


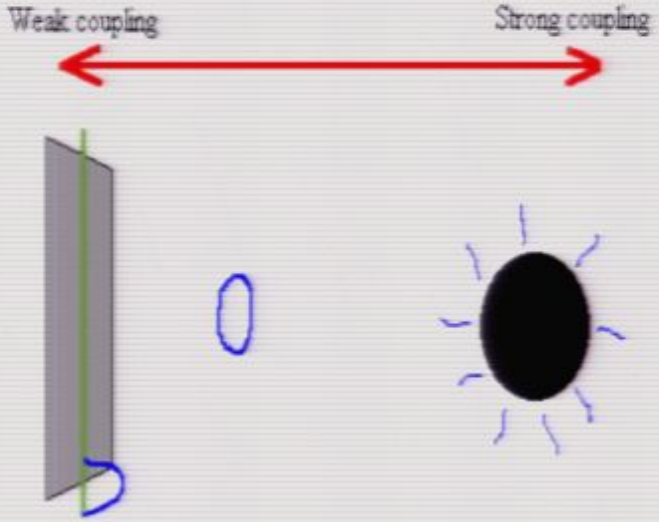


Black hole made by D-branes

Hawking radiation

Black hole description

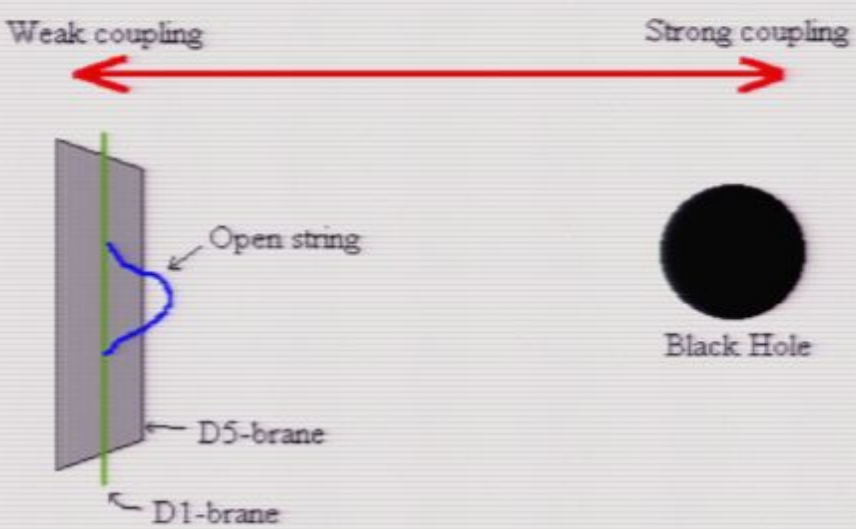


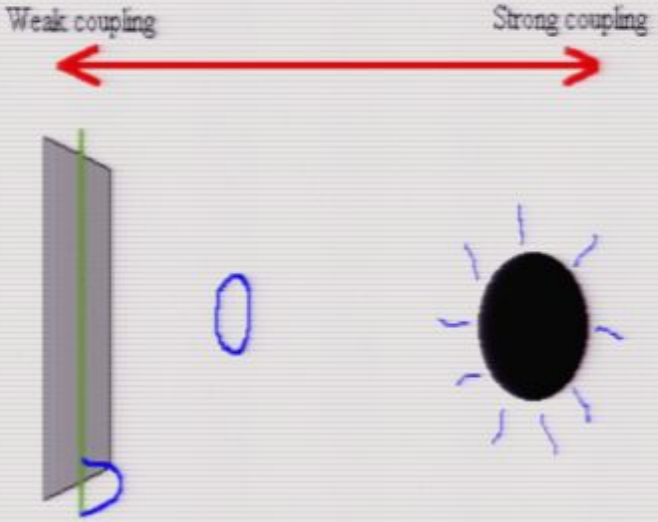


Black hole made by D-branes

Hawking radiation

Black hole description

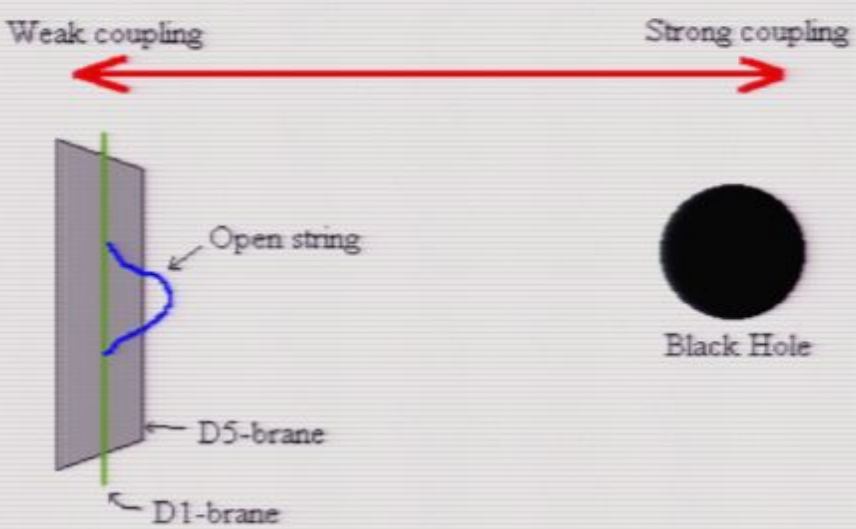


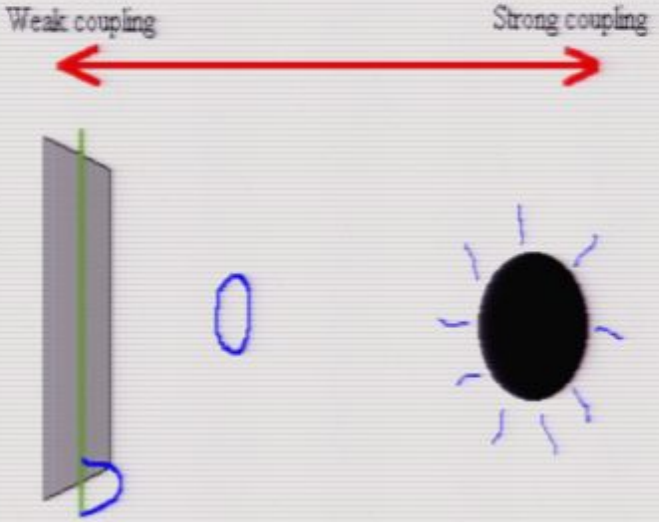


Black hole made by D-branes

Hawking radiation

Black hole description

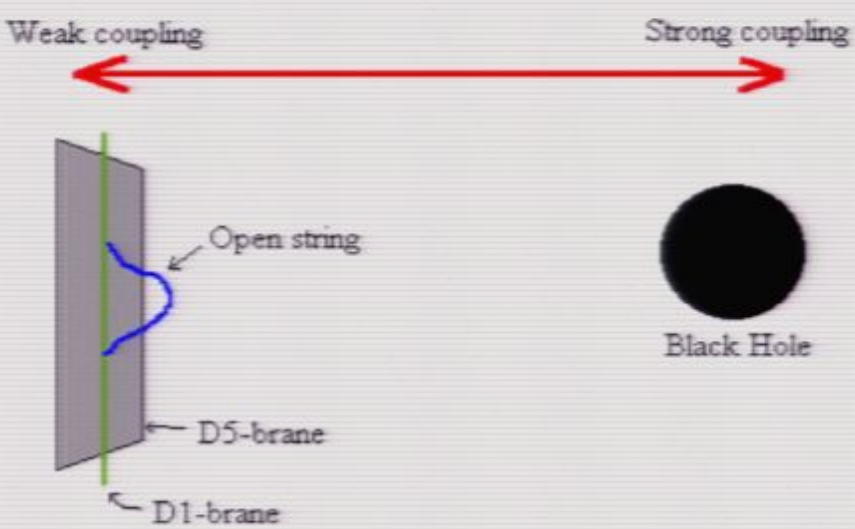


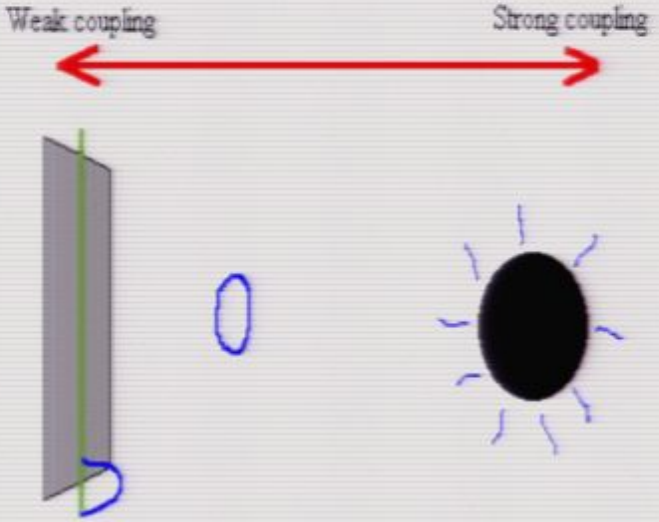


Black hole made by D-branes

Hawking radiation

Black hole description

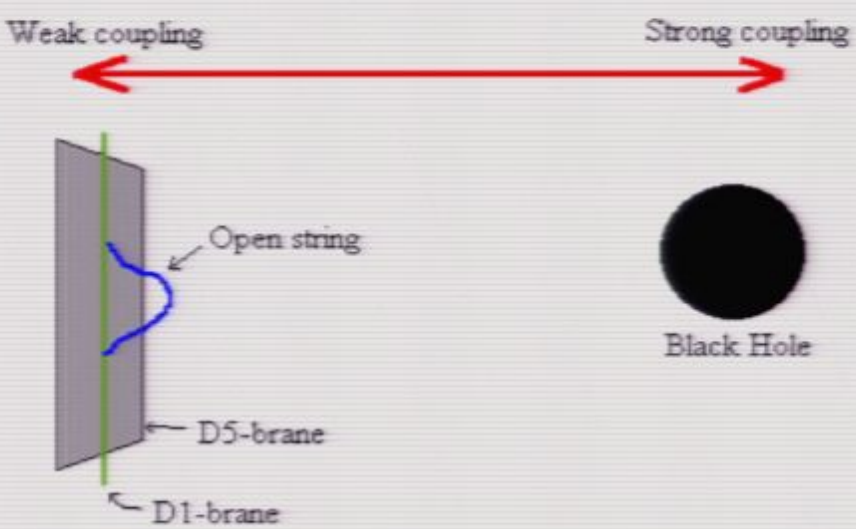


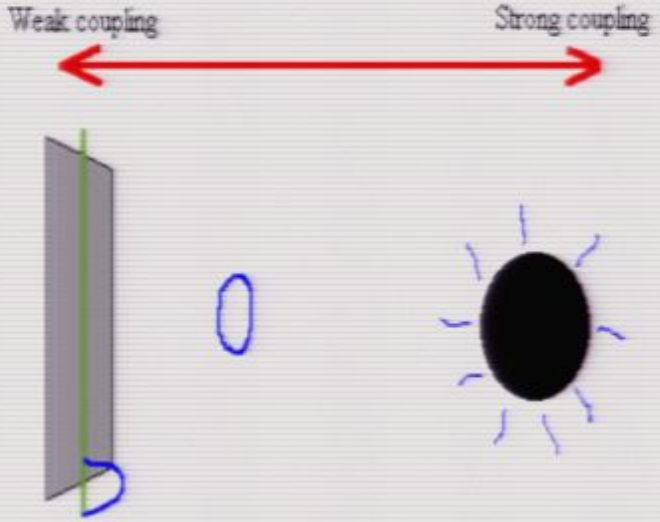


Black hole made by D-branes

Hawking radiation

Black hole description

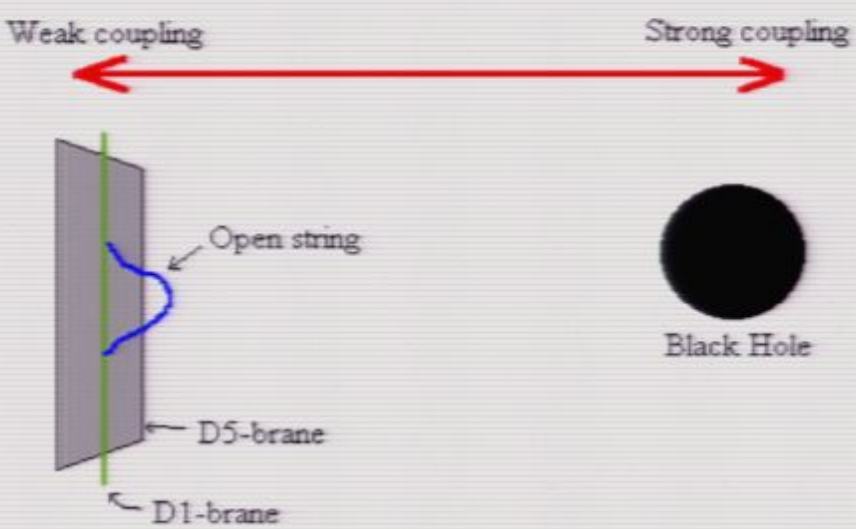


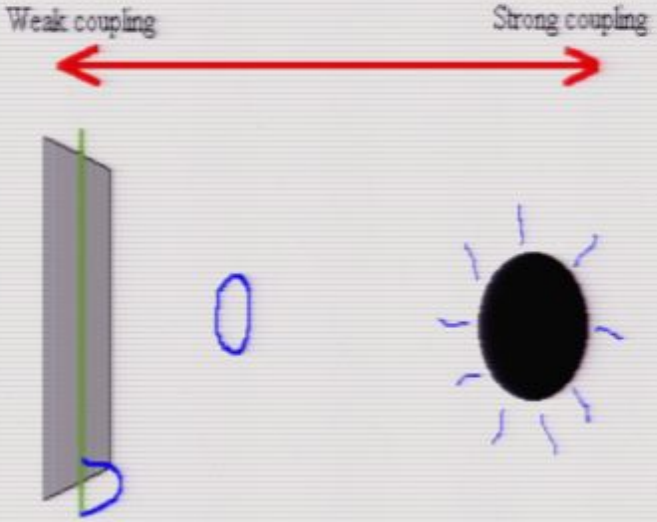


Black hole made by D-branes

Hawking radiation

Black hole description

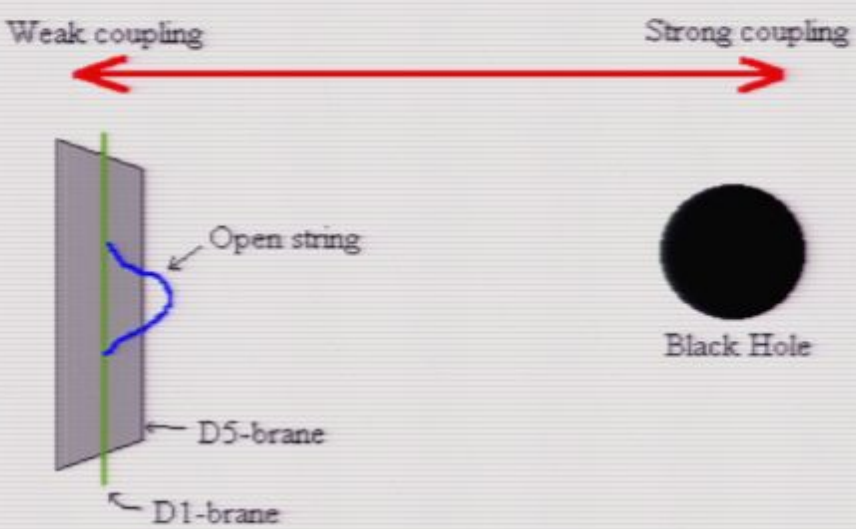


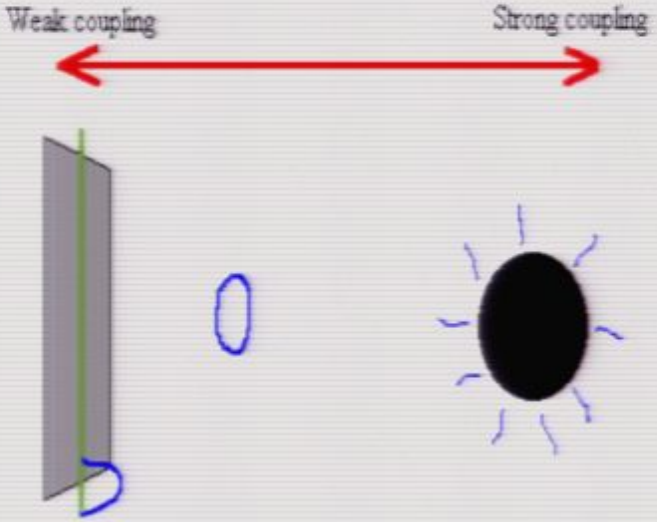


Black hole made by D-branes

Hawking radiation

Black hole description

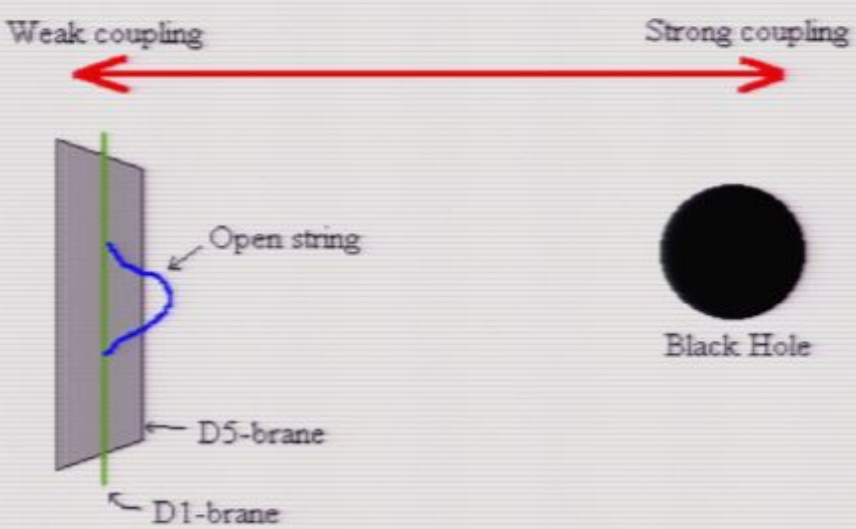


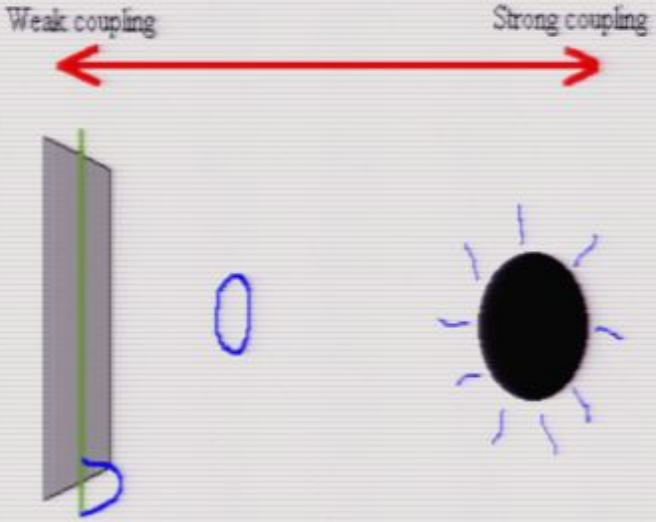


Black hole made by D-branes

Hawking radiation

Black hole description

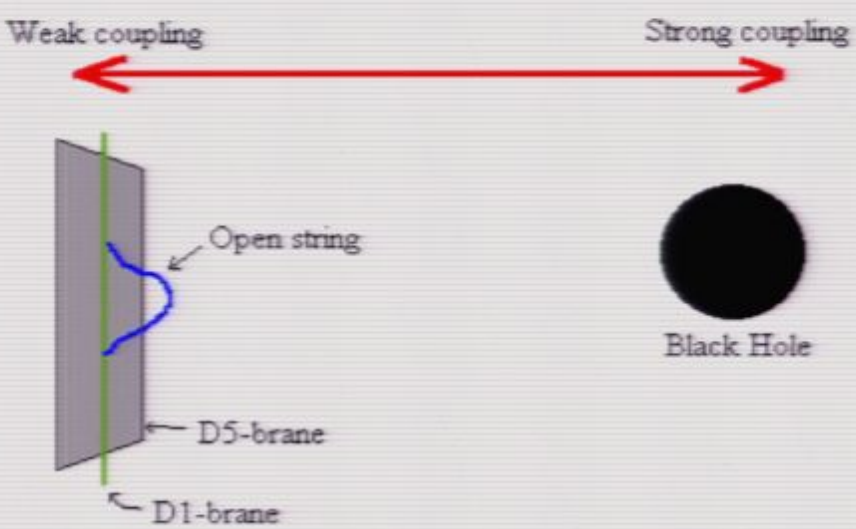


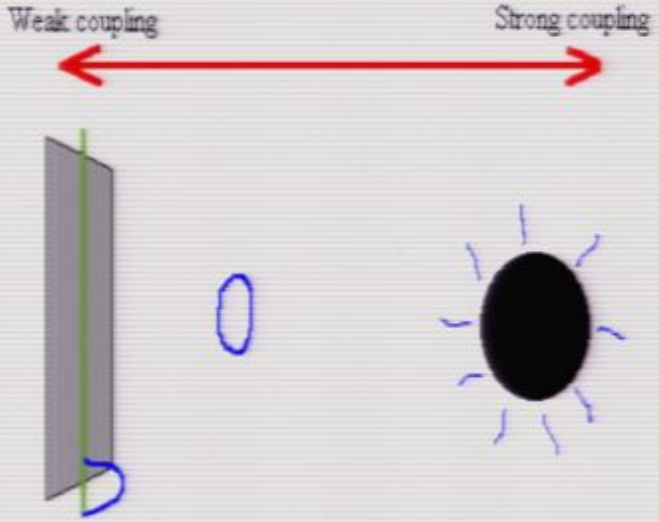


Black hole made by D-branes

Hawking radiation

Black hole description

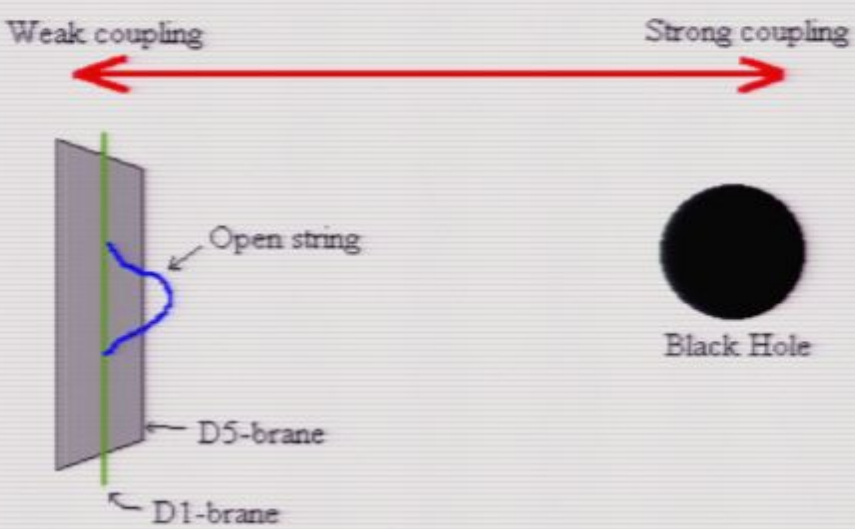


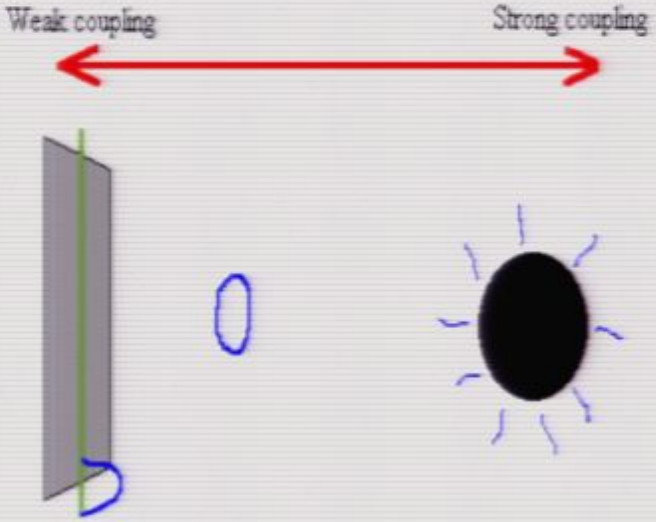


Black hole made by D-branes

Hawking radiation

Black hole description

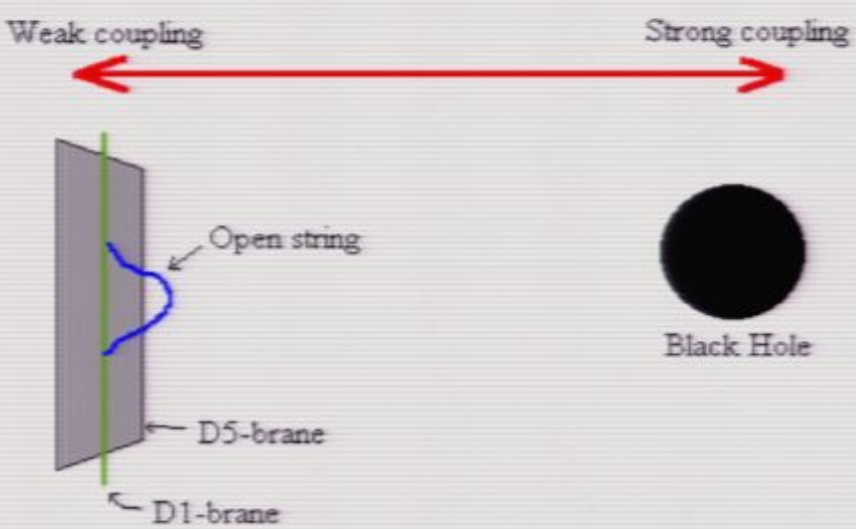


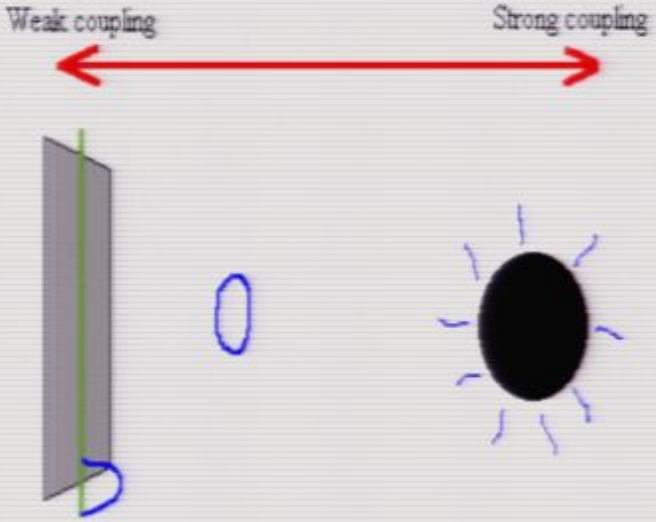


Black hole made by D-branes

Hawking radiation

Black hole description

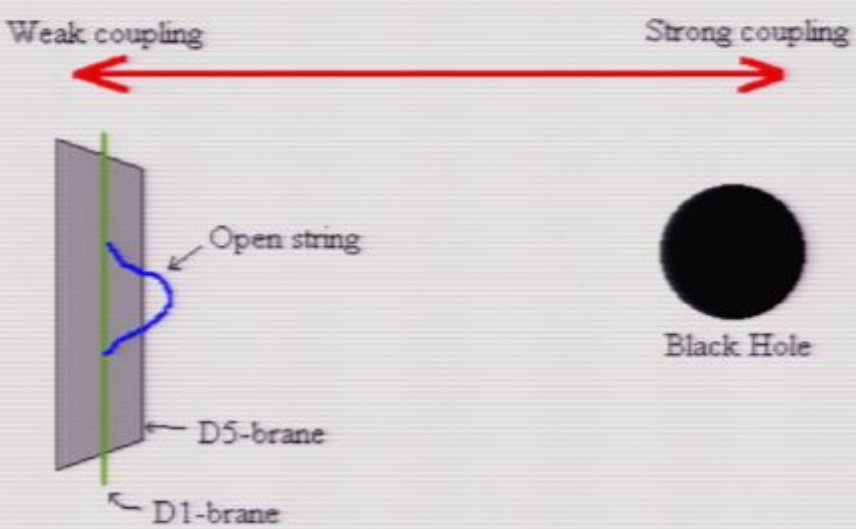


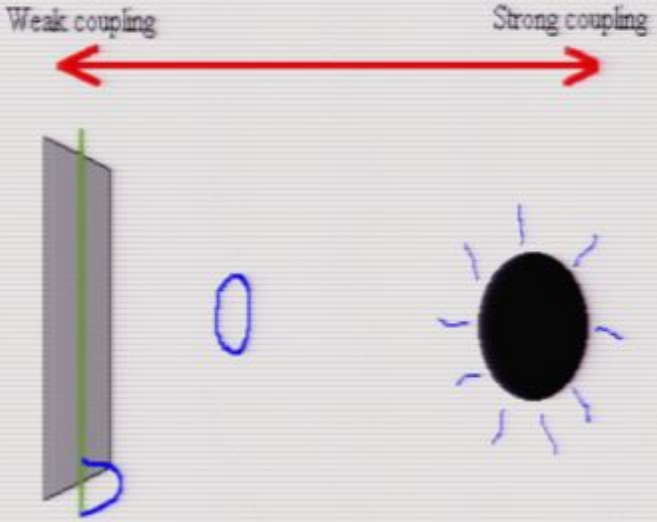


Black hole made by D-branes

Hawking radiation

Black hole description

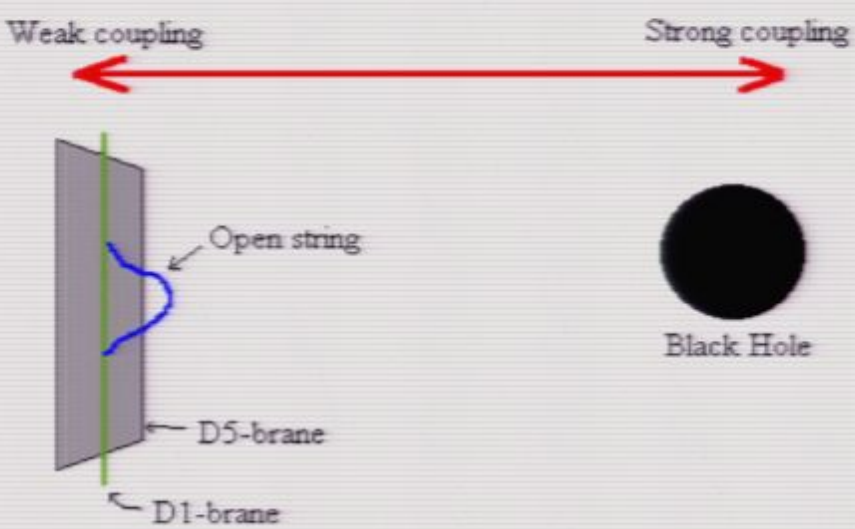


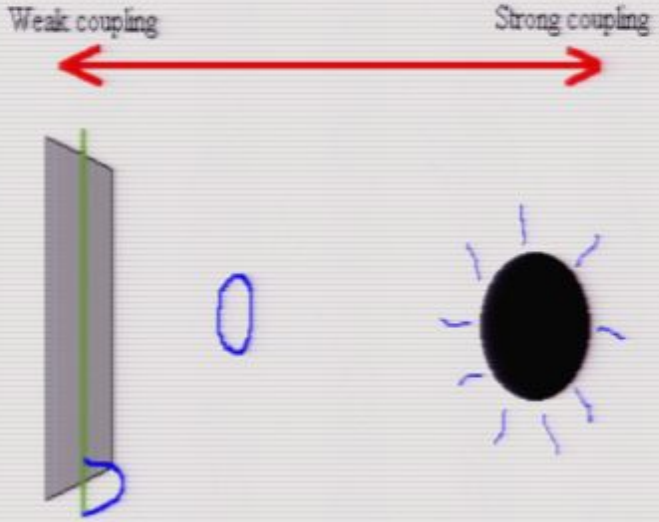


Black hole made by D-branes

Hawking radiation

Black hole description

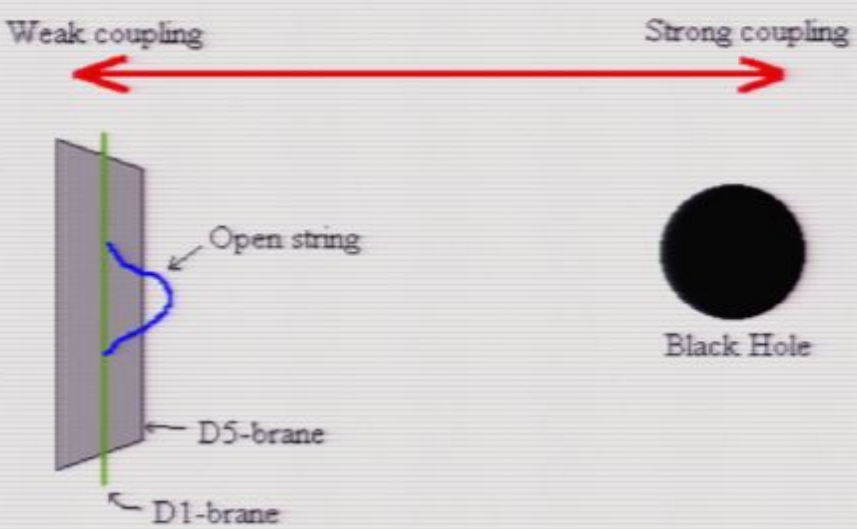


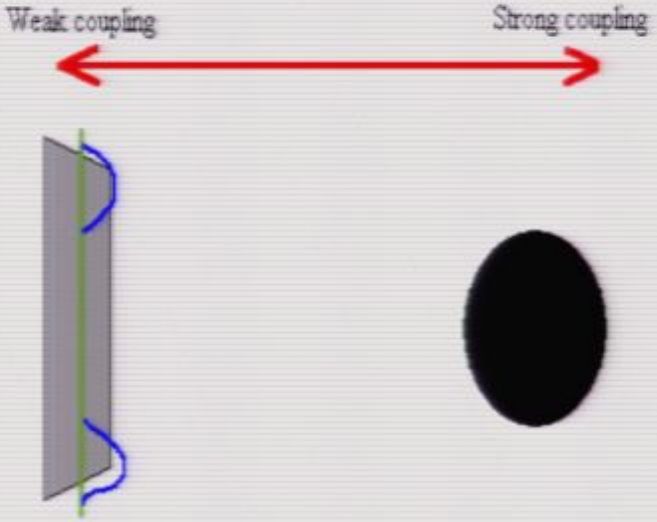


Black hole made by D-branes

Hawking radiation

Black hole description

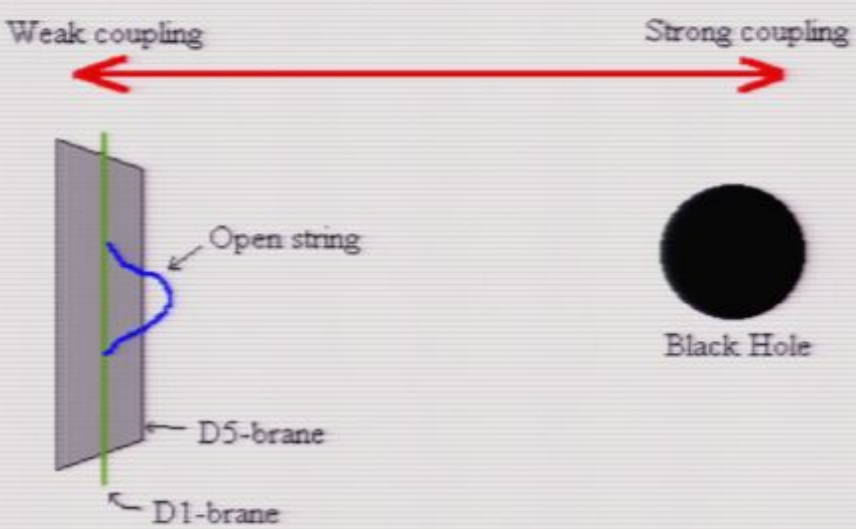


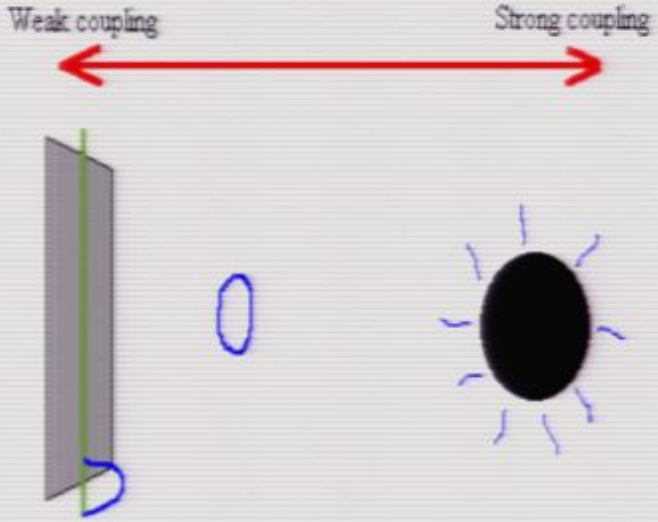


Black hole made by D-branes

Hawking radiation

Black hole description

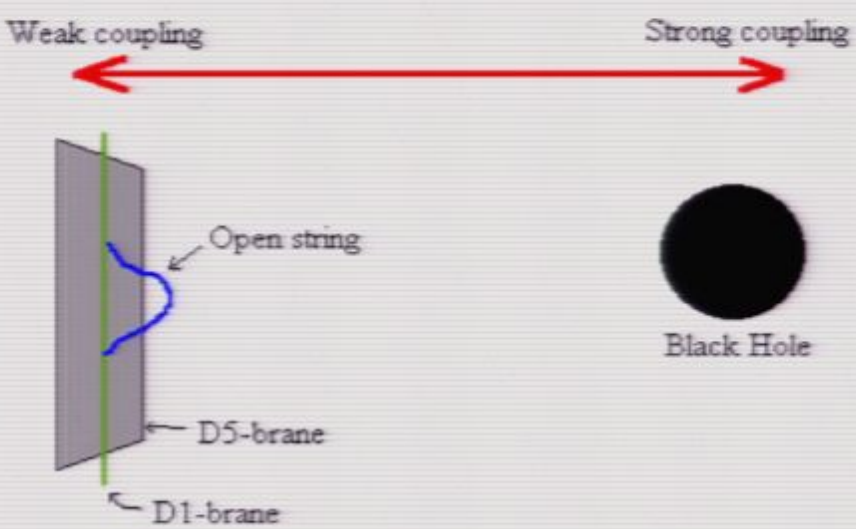


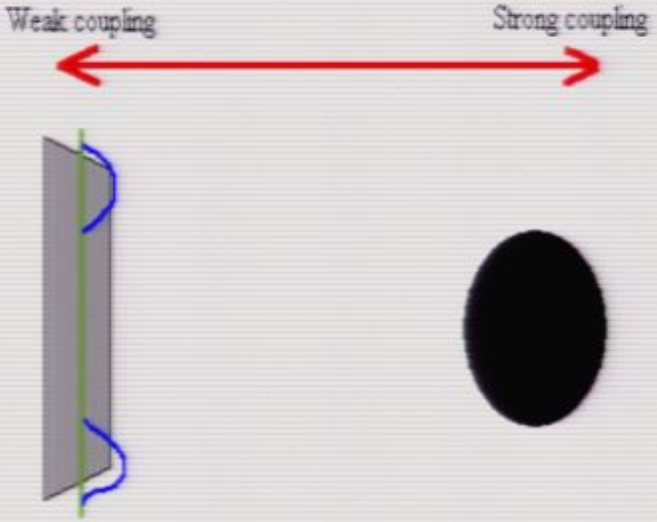


Black hole made by D-branes

Hawking radiation

Black hole description

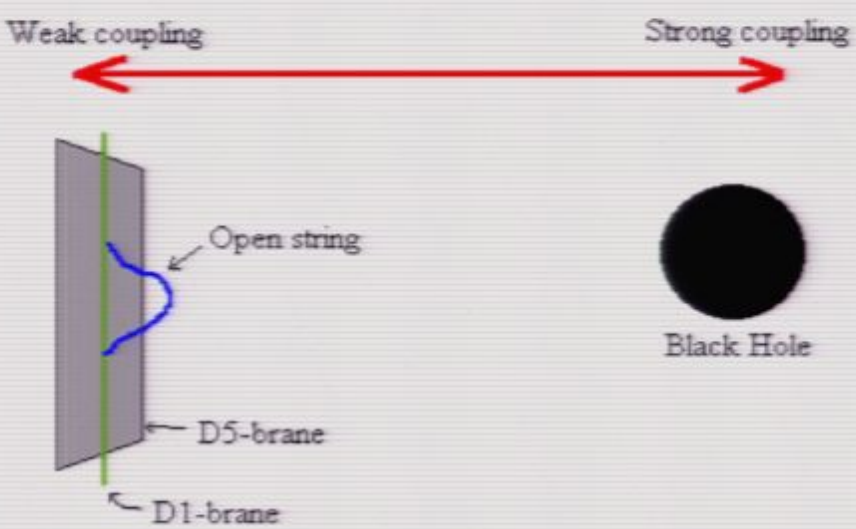


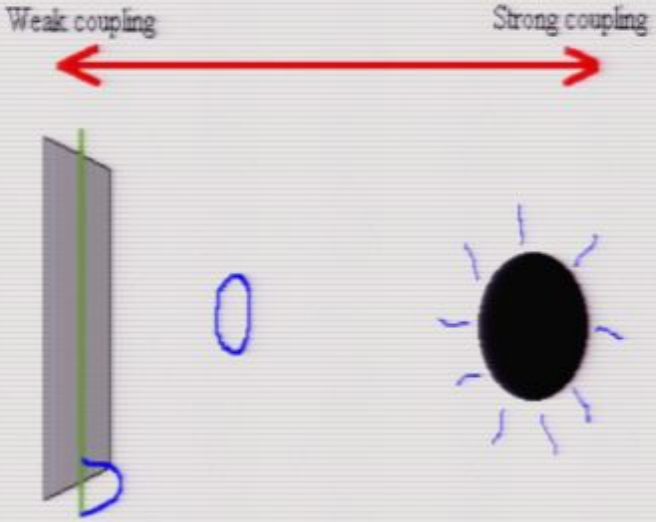


Black hole made by D-branes

Hawking radiation

Black hole description

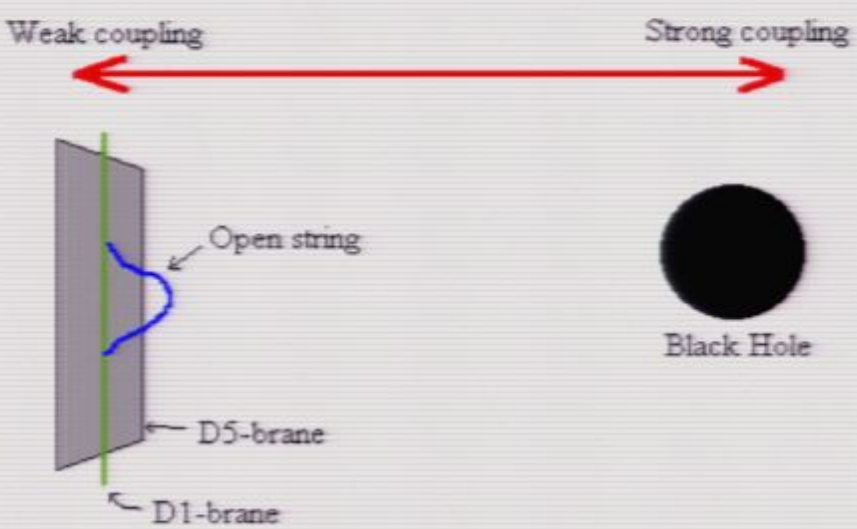


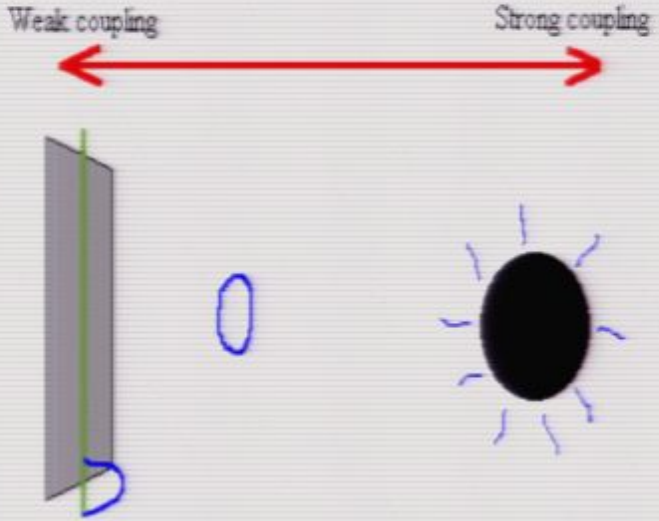


Black hole made by D-branes

Hawking radiation

Black hole description

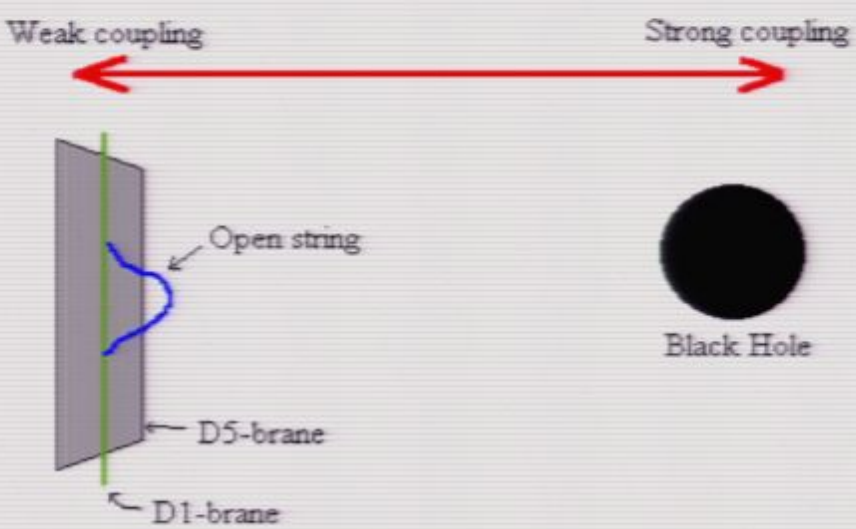


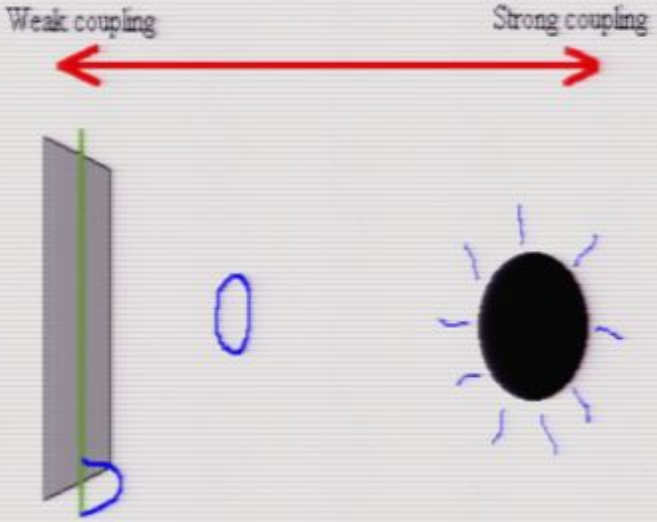


Black hole made by D-branes

Hawking radiation

Black hole description

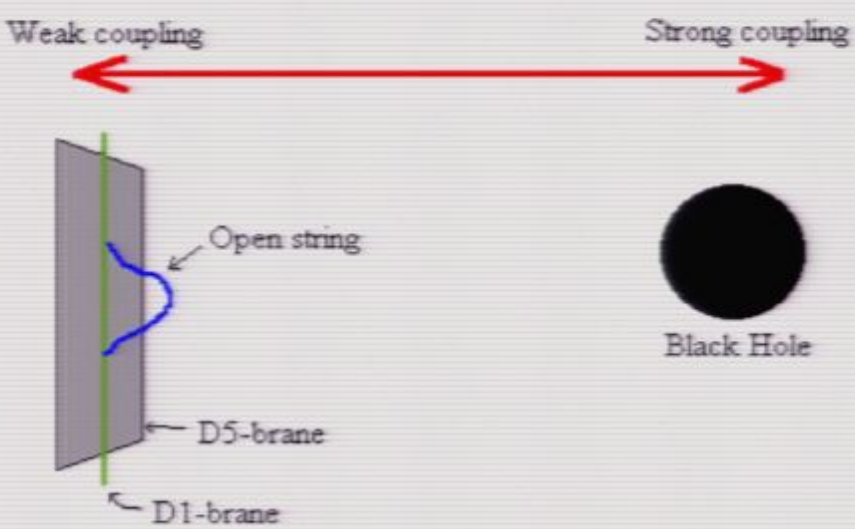


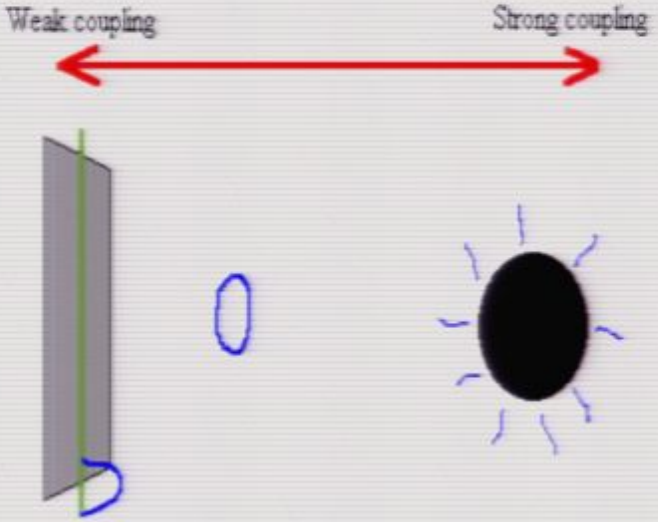


Black hole made by D-branes

Hawking radiation

Black hole description

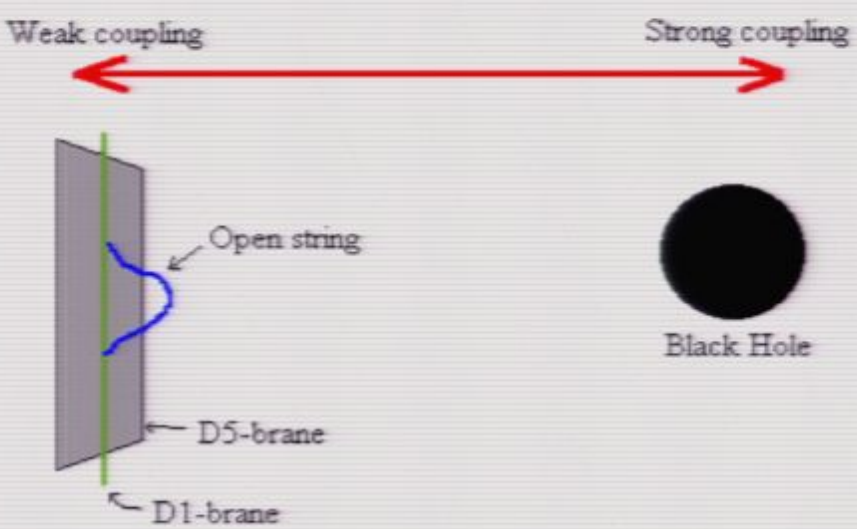


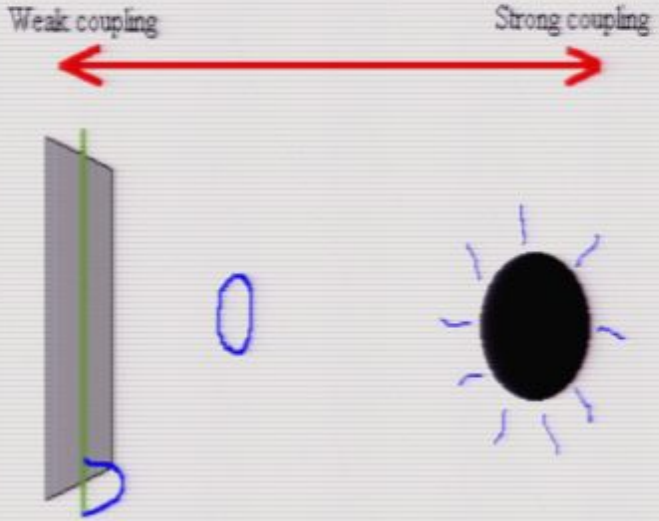


Black hole made by D-branes

Hawking radiation

Black hole description

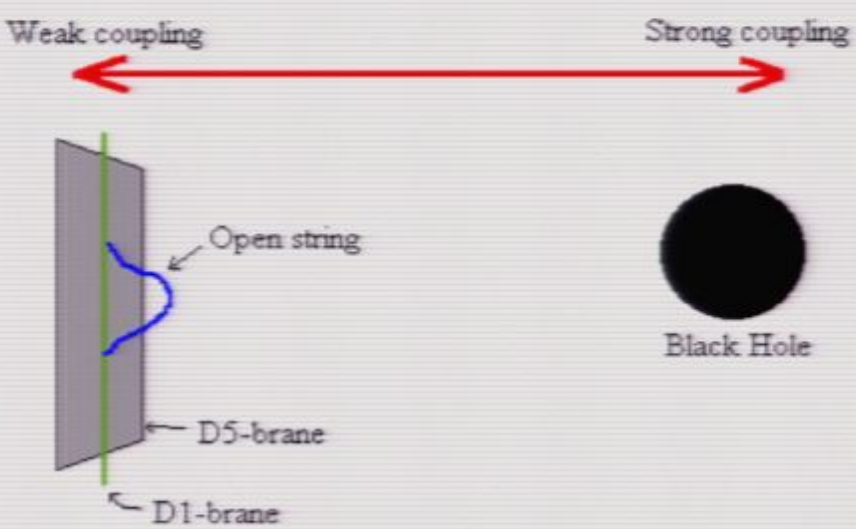


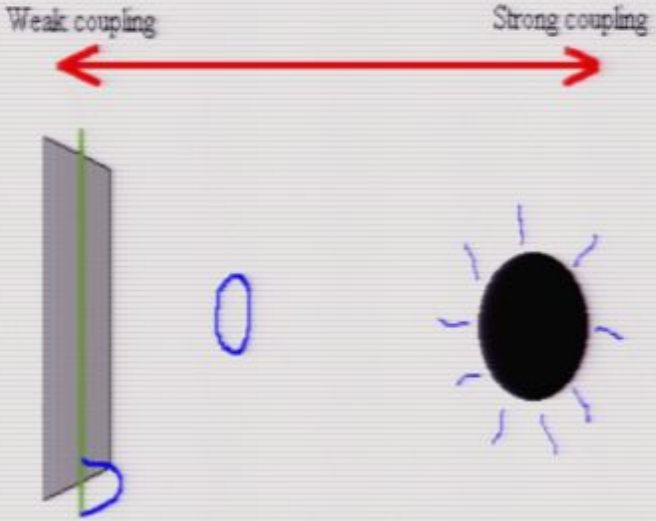


Black hole made by D-branes

Hawking radiation

Black hole description





Black hole made by D-branes

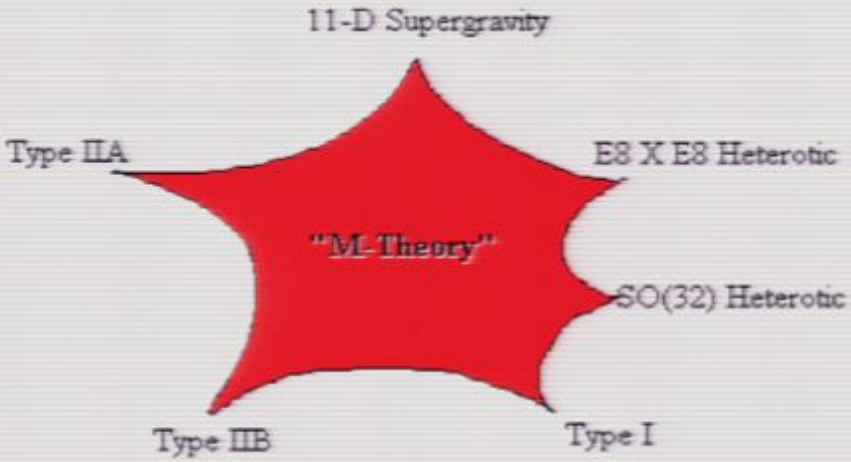
Hawking radiation

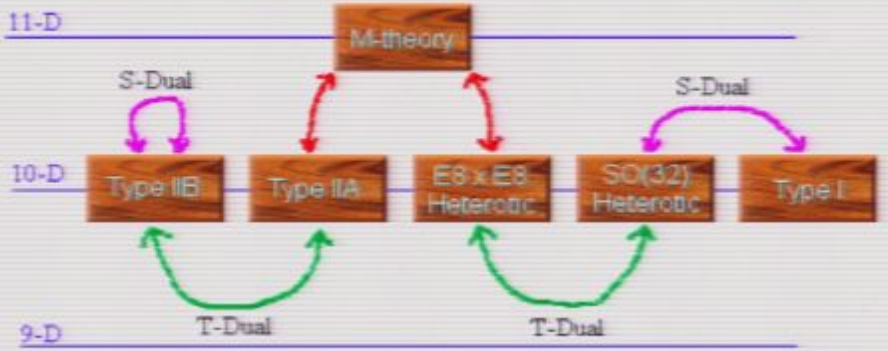
String theory summary

	Type IIB	Type IIA	E8 x E8 Heterotic	SO(32) Heterotic	Type I SO(32)
String Type	Closed	Closed	Closed	Closed	Open (& closed)
10d SUSY	N=2 (chiral)	N=2 (non-chiral)	N=1	N=1	N=1
10d Gauge groups	none	none	E8 x E8	SO(32)	SO(32)
D-branes	-1, 1, 3, 5, 7, 9	0, 2, 4, 6, 8	none	none	1,5,9

M theory




11-D Supergravity
Type IIA
E8 X E8 Heterotic
"M-Theory"
SO(32) Heterotic
Type IIB
Type I


11-D
M-theory
S-Dual
S-Dual
10-D
Type IIB
Type IIA
E8 x E8 Heterotic
SO(32) Heterotic
Type I
T-Dual
T-Dual
9-D

HOLOGRAPHY

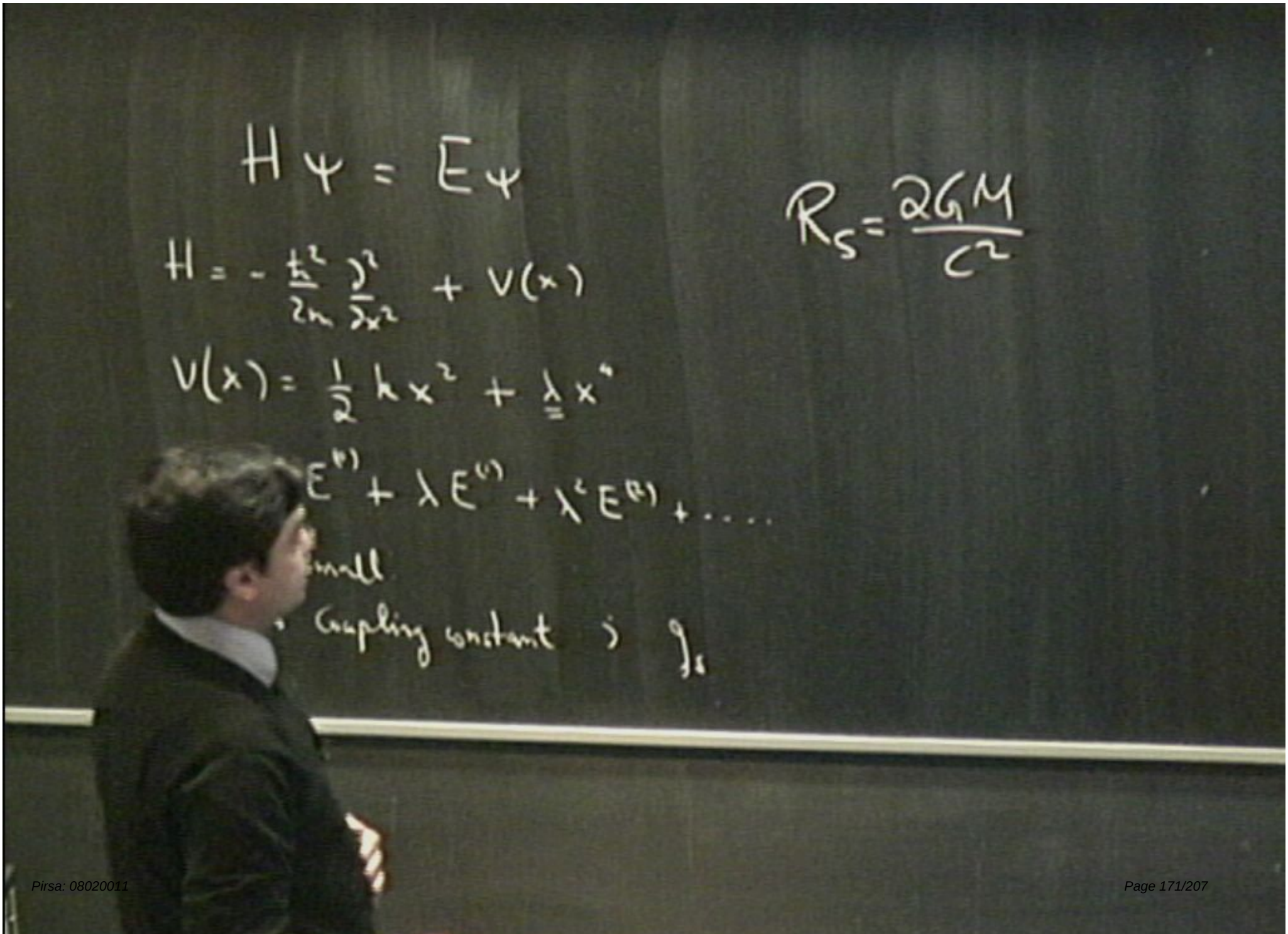
Information spreading on black hole horizon

- Conventional quantum mechanics tells us that size Δx can be probed with quanta of energy

$$\Delta E = \frac{\hbar c}{\Delta x}$$

- 21st century physics ideas give a twist in this story.
- Far above m_p high energy collision will create black hole of mass ΔE
- So short distance effects all hidden behind a horizon

$$R_S \approx \frac{2G}{c^2}\frac{\Delta E}{c^2}$$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Thus we cannot discover physics at length scales smaller than l_p

Put differently, as energy of the probe increases we will land up probing larger scales!!

$$\Delta x \geq \frac{2G}{c^2}\frac{\Delta E}{c^2}$$

Using $\Delta E \Delta t \sim \hbar$

We have a new kind of uncertainty relation

$$\Delta x \Delta t \geq \frac{2G\hbar}{c^4} \sim \frac{l_P^2}{c}$$

This is an example of **UV/IR** connection that controls relation between Frequency and spatial size. This also says that the uncertainty in the location of the particle increases as resolving time decreases.

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Entropy bounds and holography

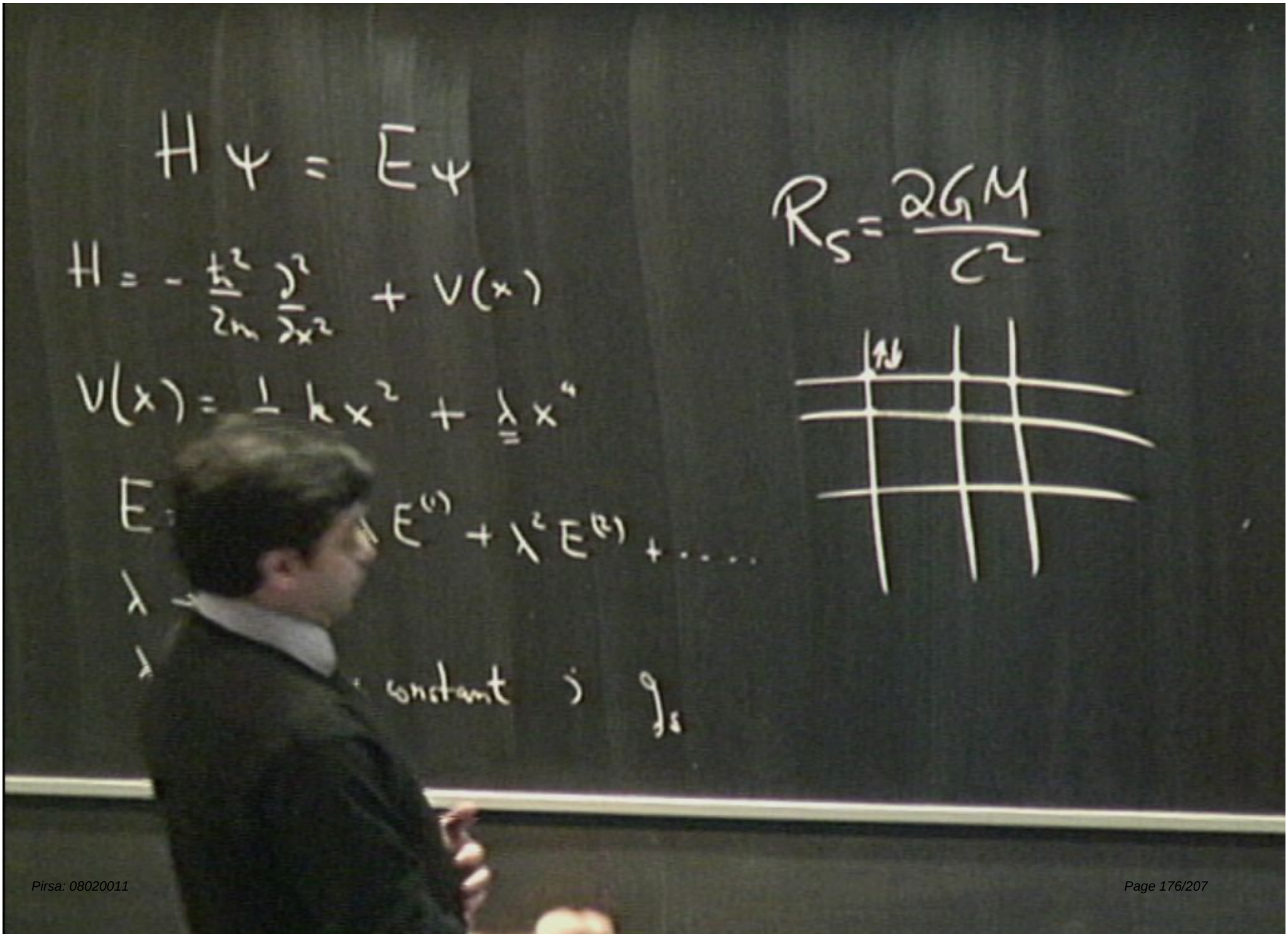
Consider a lattice with discrete up/down spins. Let lattice space be *a* and volume be *V*. Then total number of spins is V/a^3

Total number of orthogonal states is $N = 2^{V/a^3}$

Entropy is $$S = \log N = \frac{V}{a^3} \log 2$$

So S is proportional to V. This is <u>usual in quantum field theory</u>.

Intuition <u>changes when you consider gravity</u>.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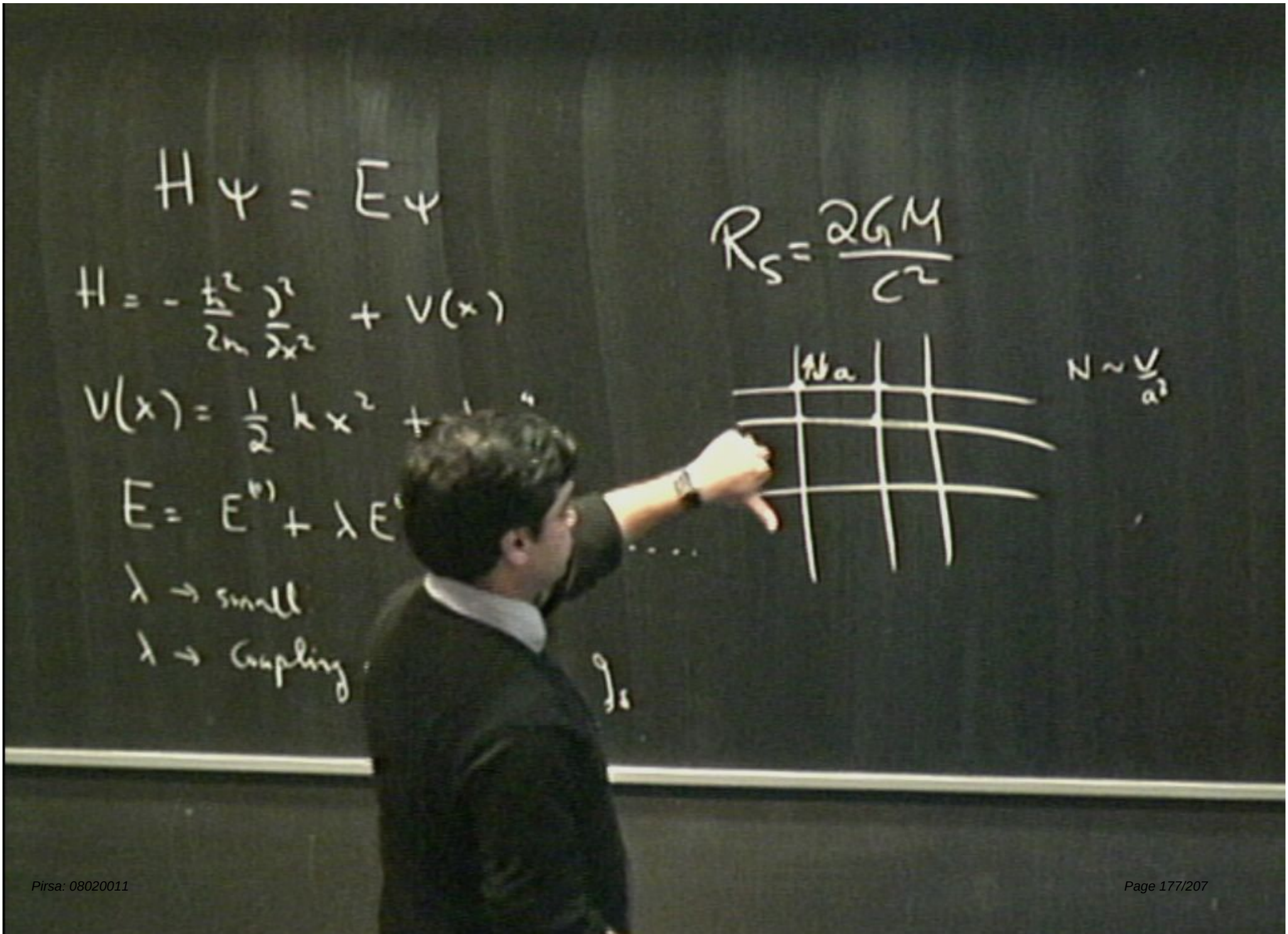
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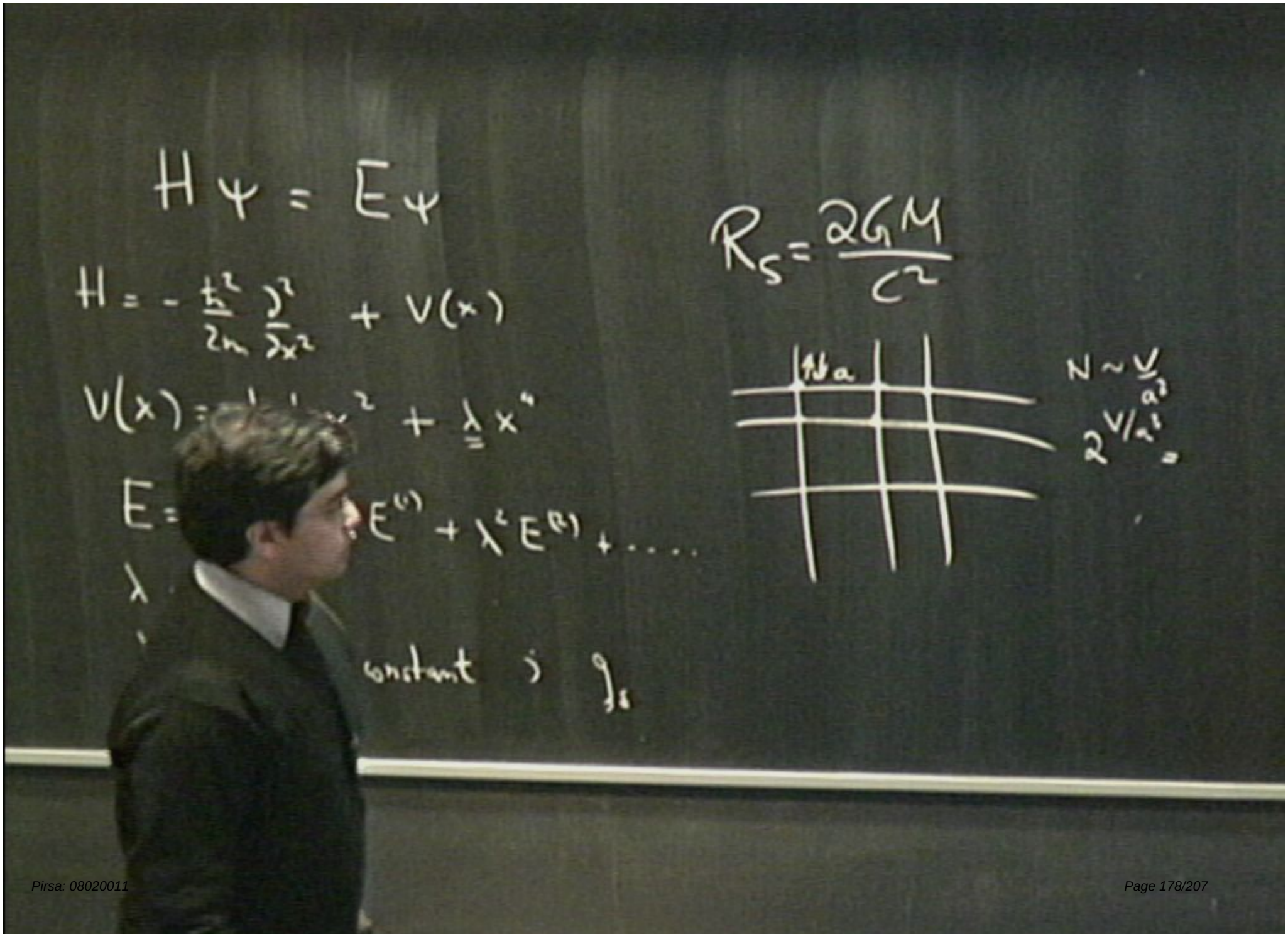
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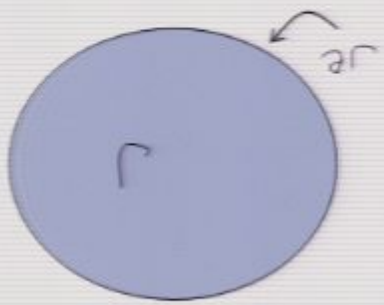

Put some mass in the region. Let's avoid forming a black hole.

Chuck in some matter to form a black hole. This results in entropy $A/4G$.

2nd law of thermodynamics says $\Delta S \geq 0$ so $S_{initial} \leq A/4G$!!

Thus we find $S \propto A$ not V.

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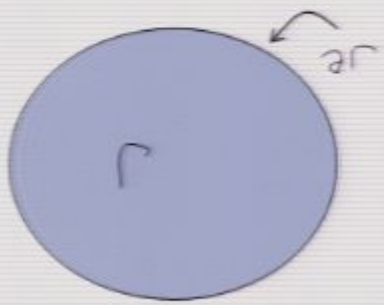

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This implies a large reduction in non-redundant degrees of freedom compared to ordinary QFT.

This can be realized by imagining degrees of freedom as living on the boundary such that no more than 1 degree of freedom/ unit Planck area.

Thus have a 3+1 spacetime with gravity described by 2+1 theory.

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A precise realization of this statement is possible from the mathematics of string theory.

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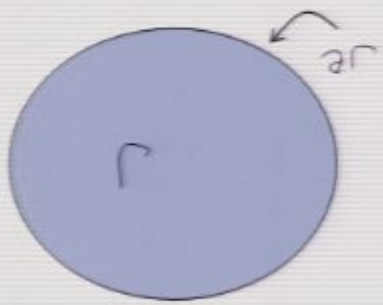

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AdS (Anti-de Sitter)/ CFT (Conformal Field Theory)

Statement of AdS/CFT

MALDACENA CONJECTURE

IIB superstring theory in $AdS_5 \times S^5$ is equivalent to $\mathcal{N}=4$, d=4 supersymmetric Yang-Mills theory with gauge group SU(N). *The gauge theory lives on the boundary of* AdS_5




$SU(3) \times SU(2) \wedge U(1)$

$$H\psi = E\psi$$

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$\lambda \to$ small

$\lambda \to$ Coupling constant ; g_s

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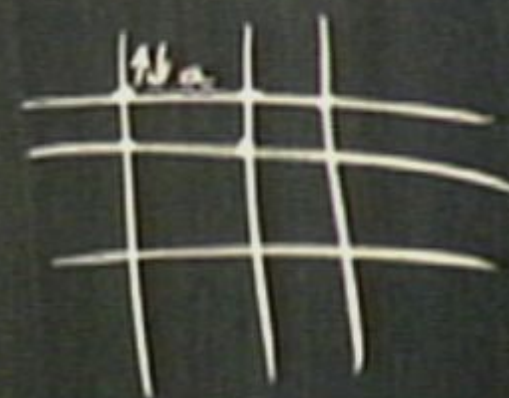

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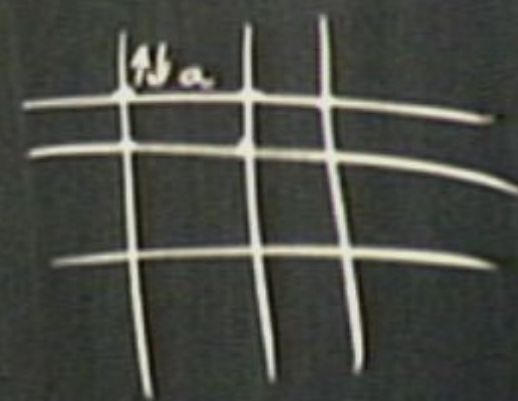

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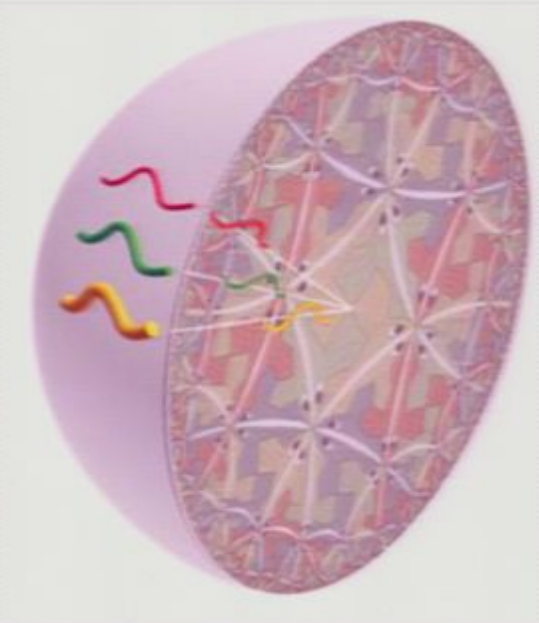
AdS/CFT in a bit more detail



Holographic theory describes how quarks and gluons interacting on the boundary of an anti–de Sitter space could be equivalent to particles in the higher dimensional interior of the space.

Source: The Illusion of Gravity by Juan Maldacena in Scientific American

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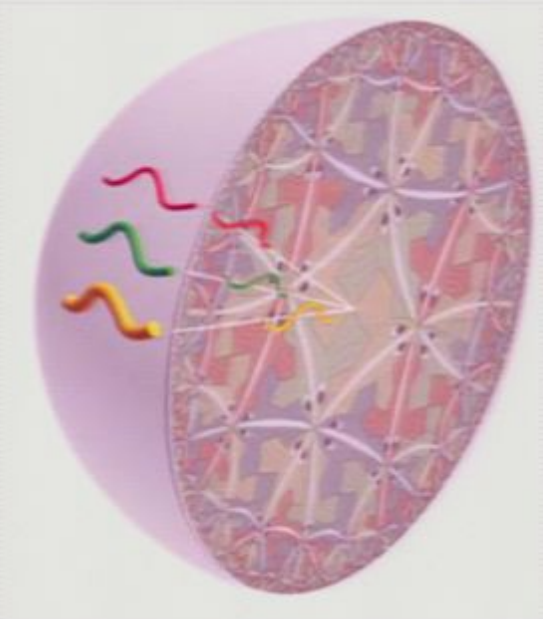

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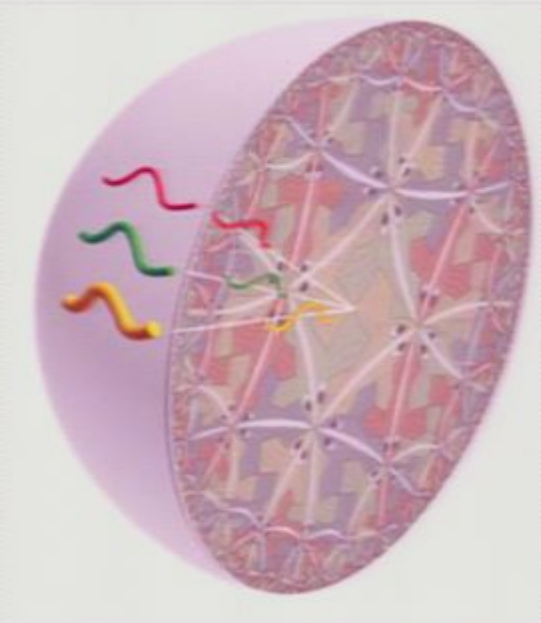

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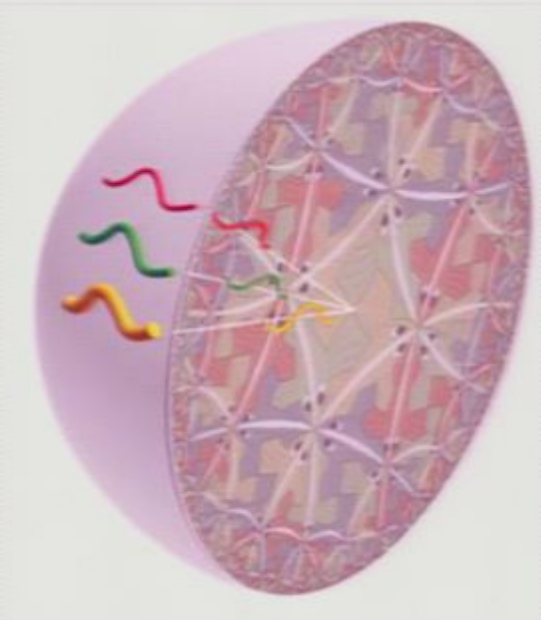
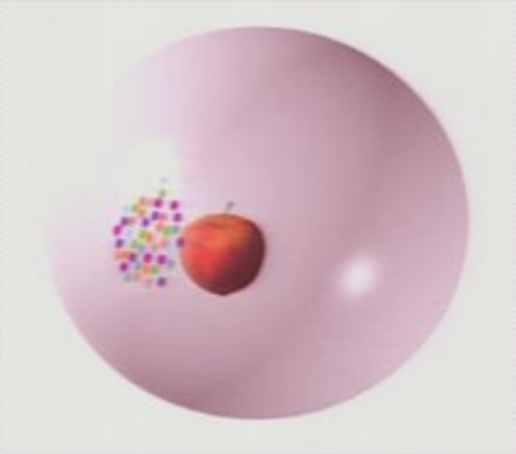


Quarks and gluons on the spherical surface of the anti–de Sitter space interact to form strings of various thicknesses. A holographic interpretation of those strings is that in the interior space they represent elementary particles (which are also strings) whose distance from the boundary corresponds to the string's thickness.

Source: The Illusion of Gravity by Juan Maldacena in Scientific American

Clouds of quarks and gluons on the boundary surface can thus describe equivalent complex objects (such as this apple) in the interior. The advantage of this holographic theory is that the interior objects experience gravity even though a distinct gravitational interaction does not exist on the surface.



AdS/CFT applications

- Using this duality, it is possible to use the string theory to extract information about the gauge theory in the regime when perturbation theory breaks down. It also works the other way. Thus hope to learn about non-perturbative gravity or non-perturbative gauge theory.

- By modifying the correspondence, it is possible to extract information at finite temperature. This is an active and exciting area of research since it enables us to study RHIC physics.

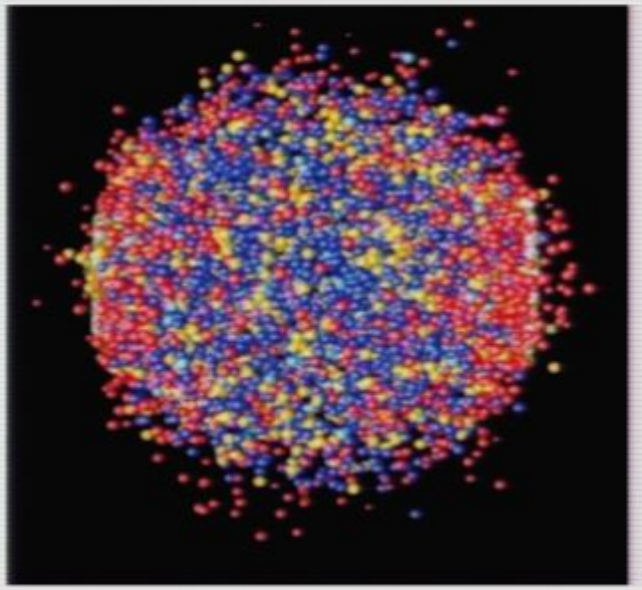
Information Please: Science news online

Information paradox

Information paradox

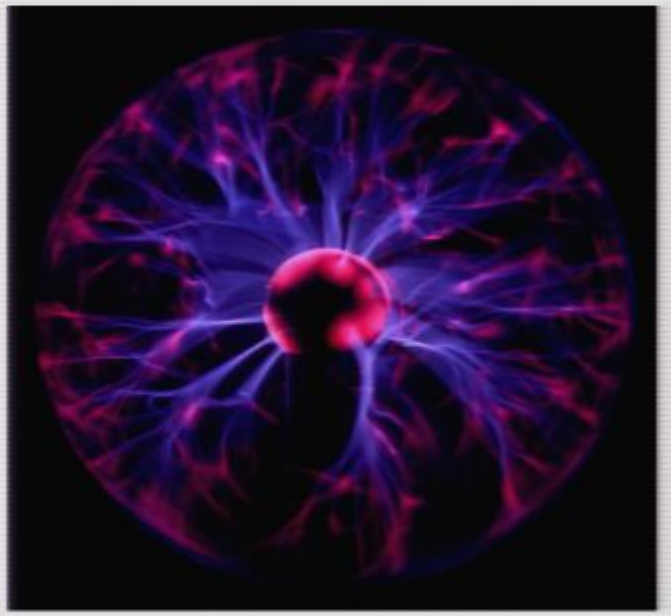
Physicist Stephen W. Hawking showed in the 1970s that black holes have a temperature and give off radiation, but physicists since then have been deeply puzzled. Temperature is a property of a collection of particles, but what is the collection that defines a black hole? The holographic theory solves this puzzle by showing that a black hole is equivalent to a swarm of interacting particles on the boundary surface of spacetime

RHIC physics and AdS/CFT



Seeking the mother of all nature: Science news online

Particles erupt out of empty space after heat from a computer-simulated, gold-gold nuclear collision destroys the vacuum's unseen structure. **(Images courtesy Brookhaven National Laboratory)**



The result of the collision is thought to be a quark gluon plasma. This plasma has a viscosity which can be calculated and measured (indirectly)

Shear viscosity from AdS/CFT

AdS/CFT predicts for the ratio of shear viscosity to entropy density $\eta/s \sim 1/4\pi \sim 0.08$

An extrapolation of the perturbative QCD prediction gives approximately $\eta/s > 1.6$

Current data compatible with $0.08<\eta/s<0.3$!!

SUMMARY

- Learnt a bit about holography ideas in gravity
- Introduced AdS/CFT correspondence in string theory
- Learnt about a few applications

PI string theory faculty

Rob Myers: Gravitational aspects of string theory. Applications of AdS/CFT to strongly coupled Quark Gluon Plasma.

Jaume Gomis: Understanding the holographic dictionary. Non-perturbative aspects of gauge theories.

Freddy Cachazo: New tools to develop understanding of perturbative gauge theories with applications to AdS/CFT.

Alex Buchel: String cosmology, understand inside of black hole. AdS/CFT methods related to strongly coupled Quark Gluon Plasma

Homework problems

- Find gravity dual for QCD
- Find a way to compute 1/N corrections
- Make some prediction using the duality
- PROVE THE DUALITY

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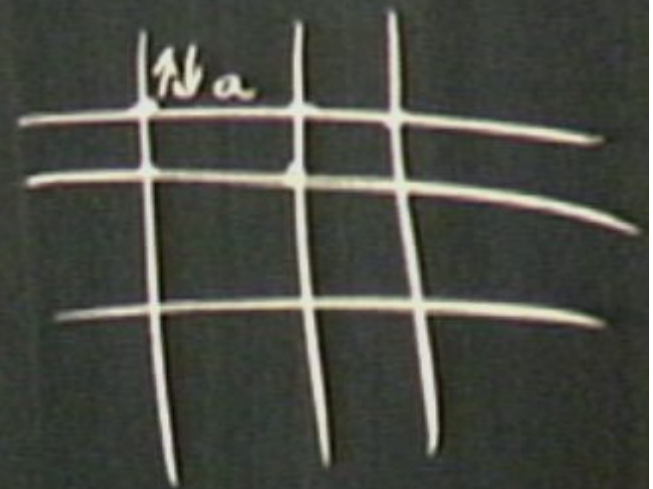

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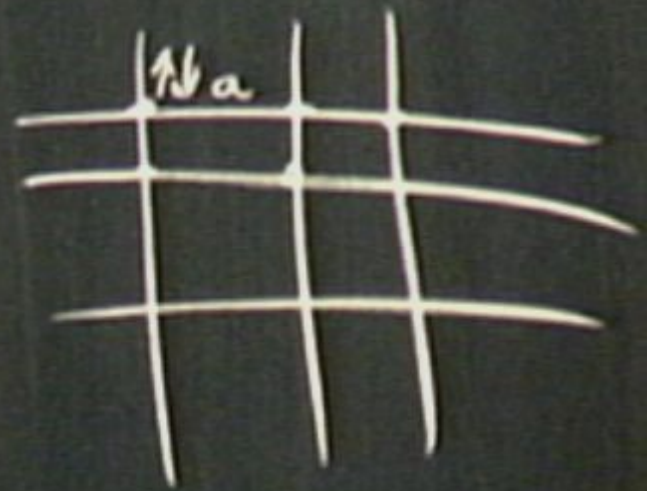

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