



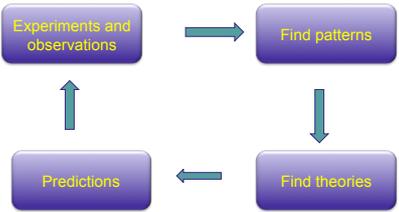
How the Superstring Works

Hisao Suzuki, Hokkaido University

Questions

- ❖ How did our universe begin?
- ❖ Why are we here?
- ❖ Are these scientific questions?
- ❖ Evolution of the universe was not scientific question about 100 years ago.

Scientific method



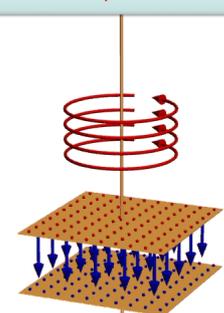
This is the standard procedure for science.

Great science discoveries have been obtained by other method.

Maxwell

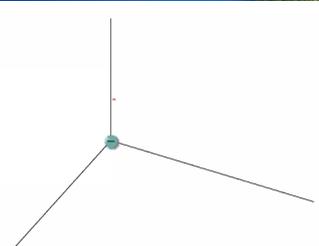
Modification of Ampère's Law



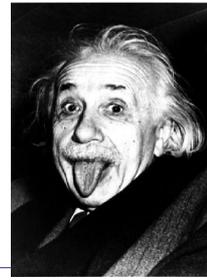


Modification is required for consistency

Prediction of EM waves



Einstein



Einstein

❖ The speed of light is constant.

The concept of the space and time was changed.

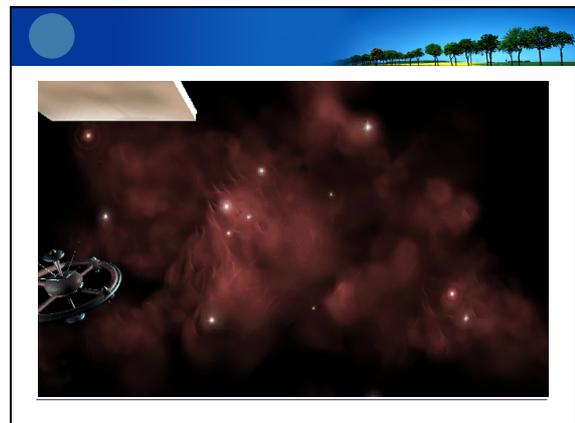
Einstein's hypothesis

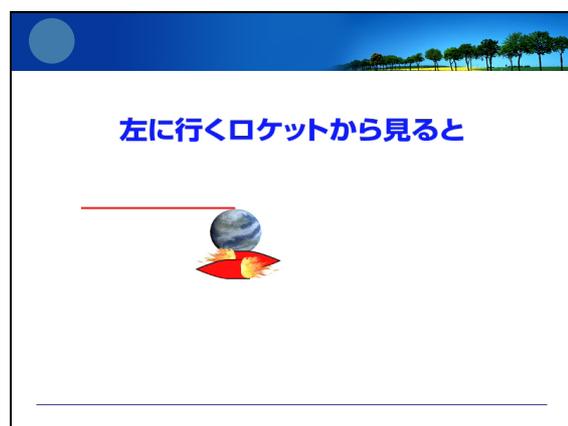
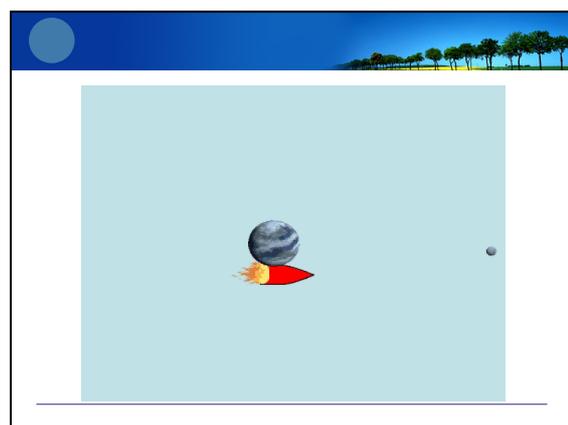
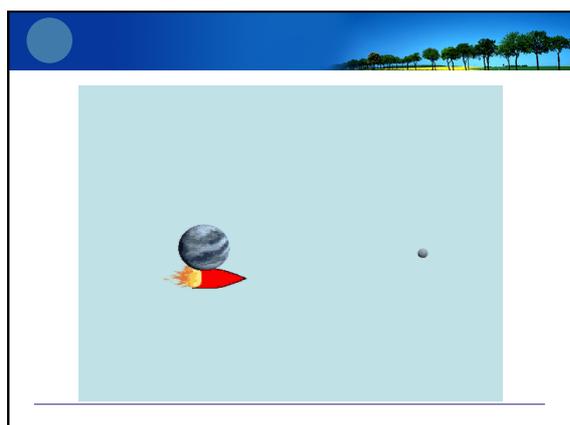
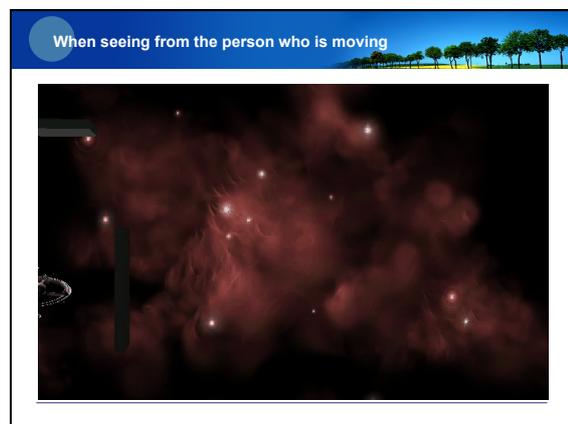
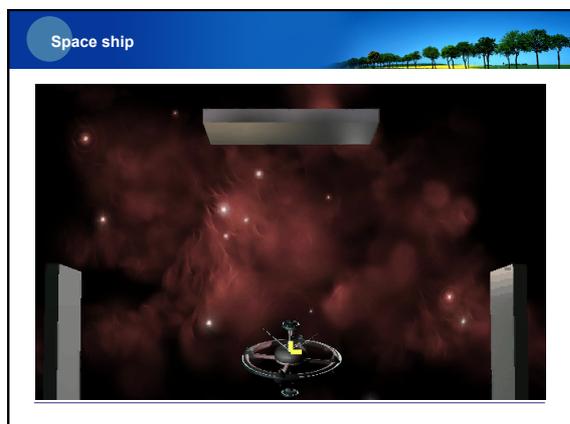
Laws of physics

Speed of light

For all system of inertias It is equal.

For all system of inertias It is equal.





Unexpected result

mass = energy

Addition of speed

❖ Understand from a addition rule.

$$\frac{v + v'}{1 + vv'/c^2}$$

The speed doesn't exceed the speed of light.

Law of universal gravitation and theory of relativity

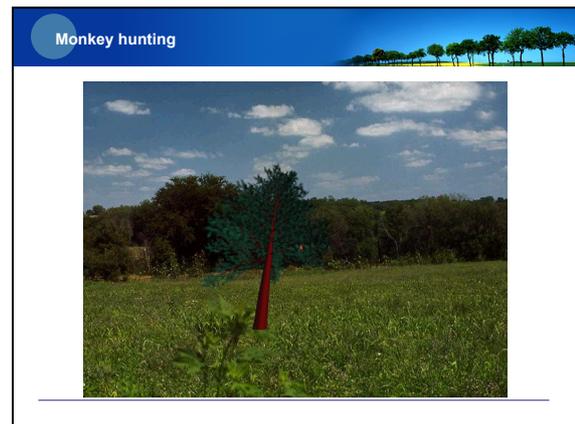
❖ Universal law of gravitation



Information Transmits instantaneously.

Contradiction

There is no notion of the simultaneous time



Principle of equivalence

❖ Monkey hunting
The person who has fallen is in a system of inertia.

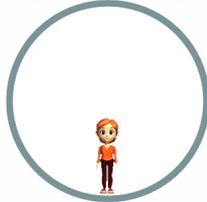
❖ The person who is standing on ground?
It is not a system of inertia.

❖ Principle of equivalence

Effect of acceleration = Effect of gravity

Gravity and acceleration

Principle of Equivalence



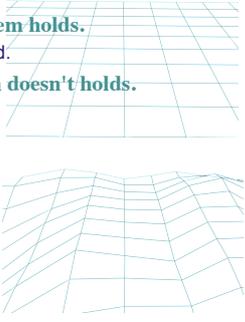
Einstein's idea

- ❖ Gravity
 - I do not feel gravity in the person who has fallen.
 - Gravity is not force.
- ❖ What is the gravity?



Space

- ❖ If Pythagorean theorem holds.
The space is not curved.
- ❖ Pythagorean theorem doesn't holds.
Is the space curved?

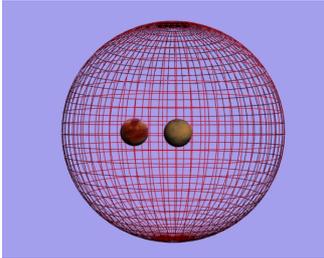


Unexpected results

Evolution of the universe

Black holes

Movement of objects in curved space



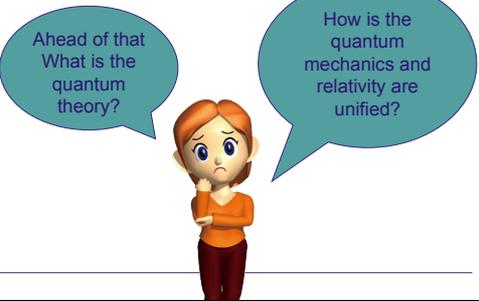
Bending of time-space and bending of light

- ❖ The speed of light is different in each point.



Uniting of quantum theory and theory of relativity

- ❖ The quantum theory and theory of relativity



Ahead of that
What is the quantum theory?

How is the quantum mechanics and relativity are unified?

Quantum theory

❖ Interference experiment of electron

electron gun slit screen

Special relativity and quantum mechanics

❖ Theory by Dirac

Quantum mechanics and relativity are united.

Negative energy particles are necessary.

Is it good when doing very?

Interpretation of electron of negative energy

❖ Interpretation

Energy

mc^2

$-mc^2$

position

Electrons having negative energies

Dirac hole theory

Prediction of antiparticle

Disadvantage of Dirac theory

- ❖ What is the interaction of electrons within Sea?
- ❖ Essentially many body system.
- ❖ Theory does not have particle antiparticle symmetry.

Pauli

Quantum field theory

photon

photon

positron

electron

Quantum field theory predicts that we should treat infinite number of particles even for hydrogen atoms.

Electromagnetic forces

Photon

Electronic proton

Self energy of electron

Watch out!
Photons colliding to electrons!

We can come back as soon as possible

photon

electron

I can't go!

Infinitely massive

It carries it over with the self energy of the electron.

実際の電子

There is no electron without electric fields!

with electric fields

almost massless with huge EM energy

Physical mass

Renormalization

Tomonaga
Schwinger
Feynman

Quantum Electrodynamics

One of the most successful theory in particle theory

But what is the value of bare mass?

General theory of relativity and quantum theory

With general theory of relativity the quantum theory is contradictory.

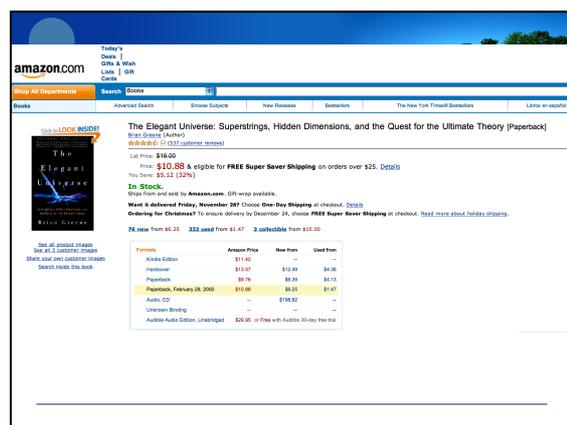


Renormalization does not work

About string books



Are there any good books about string?



The Elegant Universe: Superstrings, Hidden Dimensions, and the Quest for the Ultimate Theory (Paperback)
 Brian Greene (Author)
 1999-01-01 (1997 Customer review)
 List Price: \$16.00
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Paperback, February 26, 2000	\$10.98	\$8.25	\$1.47
Audi CD	—	\$19.00	—
Unknown Binding	—	—	—
Audible Audio Edition, Unabridged	\$29.95	or Free with Audible 30-day free trial	—



String Theory, Book 1: Cohesion (Star Trek, Voyager) (Bk. 1) [Mass Market Paperback]
 Jeffrey Lang (Author)
 2006-01-01 (252 customer reviews)
Available from these sellers.
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Kindle Edition	\$3.99	—	—
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- Star Trek: Voyager: Unworthy (Star Trek, Voyager) by Kirsten Beyer **\$7.99**
- Star Trek: Voyager: Full Circle (Star Trek, Voyager) by Kirsten Beyer **\$7.99**



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 Michael Allen (Author), Robert Gillespie (Author), Pamela Tellejohn Hayes (Author), John Higgins (Editor)
 1999-01-01 (19 customer reviews)
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 Camilla Gryski (Author)
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Paperback, September 1996	--	\$34.99	\$0.01

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Is bare mass of the electron infinitely small?

❖ The same recipe cannot be used for gravity.



string theory

point particle

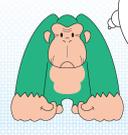
High Resolution

String

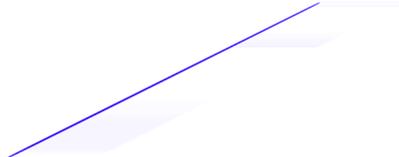
Why should we consider string theories?

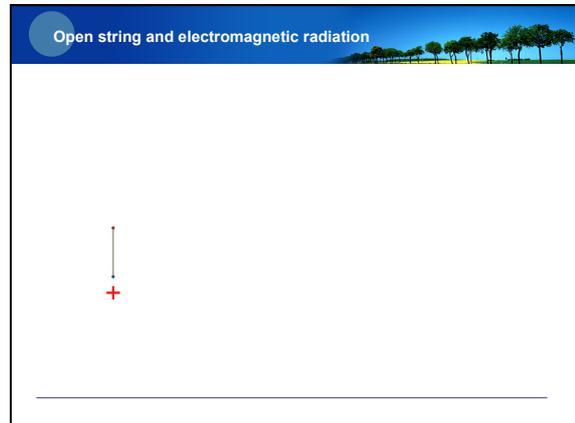
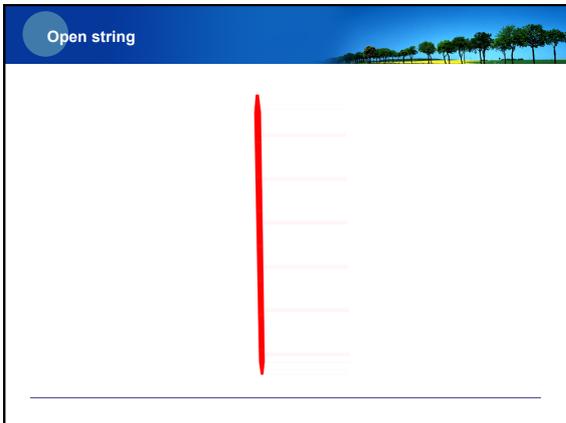
$l_p = \sqrt{\frac{\hbar G}{c^3}}$

10^{-33} cm

Superstring theory





Why photons does not have longitudinal mode?

- ❖ Lorentz contraction
- ❖ Length to the direction of motion is zero if it moves at a speed of light
- ❖ There is no vibration to the direction of velocity

Watch out!
Photons colliding to electrons!

We can come back as soon as possible

photon

electron

I can't go!

Infinitely massive

There is no divergence in the string theory.

Closed strings have No divergence!

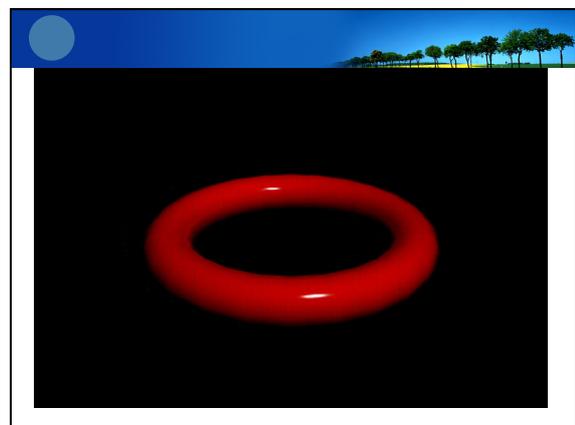
Let's try to come back soon

Painful

Painful

I can't come back sooner

string can propagate



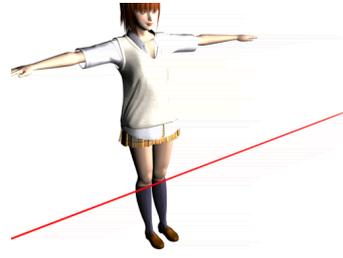
The string theory is a theory of ten dimensions.

❖ Ten dimensions

What if we cannot see the directions other than 3 dimensions?



Direction not seen



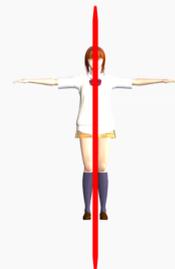
Vibration of string

Gravitational mode becomes photon
In our space-time

Open string?

For an open string

Do when seeing from the right under?



For an open string

Do when seeing from the right under?



Vibration of strings and the unification of particles and forces

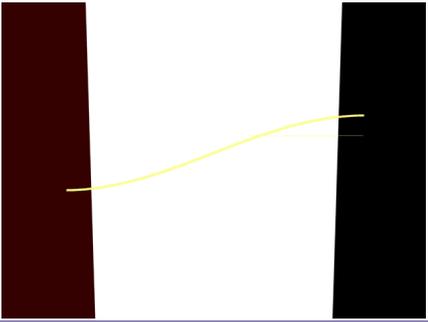
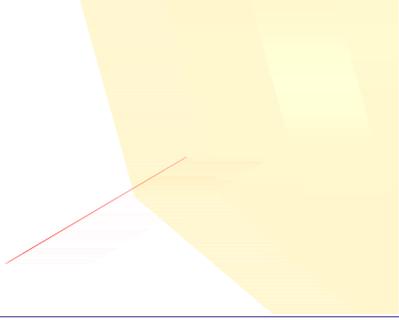
In ten dimensions	In our space-time
 <p>x direction</p>	 <p>Graviton To general relativity</p>
 <p>y direction</p>	 <p>photons gluons weak bosons</p>
 <p>x direction</p>	
 <p>Internal direction</p>	 <p>Matter fields</p>

Unified force theory

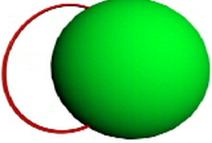
❖ Superstring theory is an unified force theory of the forces and the particle.



D-brane

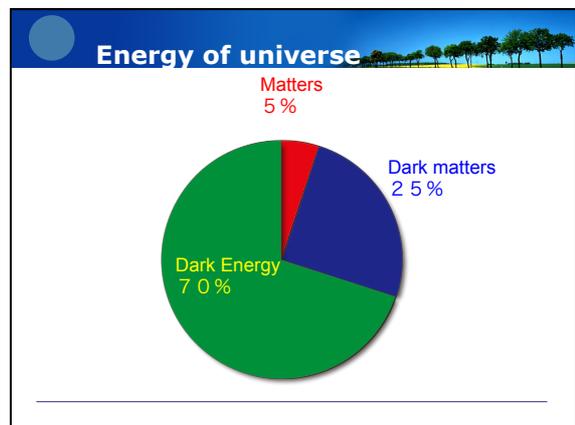


Phase transition



Problems

❖ There are many problems in string theory.



Perturbation of Cosmic Microwave Background

Inflation

Are there any natural candidates for inflaton?

エネルギー

Effect of Inflation

Are there any natural candidates for inflaton?C

It is not natural to get the standard model in string

Quantum theory of gravity

Quantum theory of gravity

It has not been completed yet.

Superstring theory
Let's complete it.

End