



What's String Theory?



What's String Theory?

String theory is ...

- A branch of physics where we try to reconcile
 - gravity and
 - quantum mechanics.

- What's gravity?
- What's quantum mechanics?
- Why do we have to reconcile them?
- How do we reconcile them?

What's Gravity?

Mostly described by Newtonian mechanics!



https://commons.wikimedia.org/wiki/File:The_Sun_by_the_Atmospheric_Imaging_Assembly_of_NASA%27s_Solar_Dynamics_Observatory_-_20100819.jpg
https://commons.wikimedia.org/wiki/File:The_Earth_seen_from_Apollo_17.jpg
<https://apod.nasa.gov/apod/ap130301.html>

Mostly described by Newtonian mechanics!



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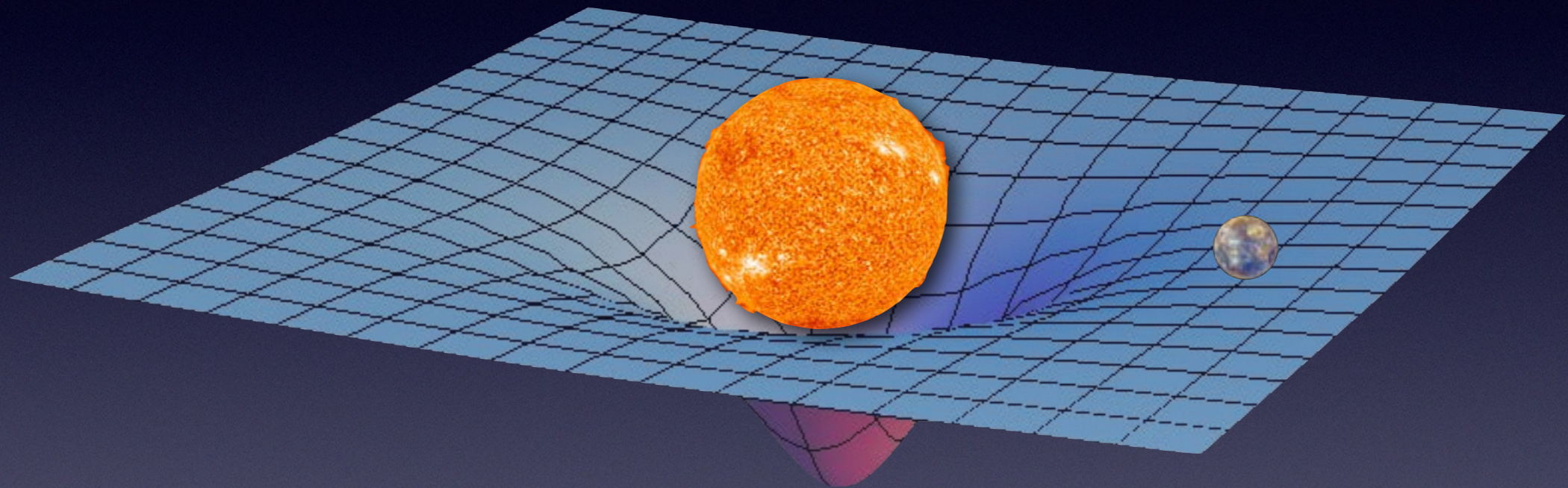
Motion of Mercury deviates significantly from it.

https://commons.wikimedia.org/wiki/File:The_Sun_by_the_Atmospheric_Imaging_Assembly_of_NASA%27s_Solar_Dynamics_Observatory_-_20100819.jpg

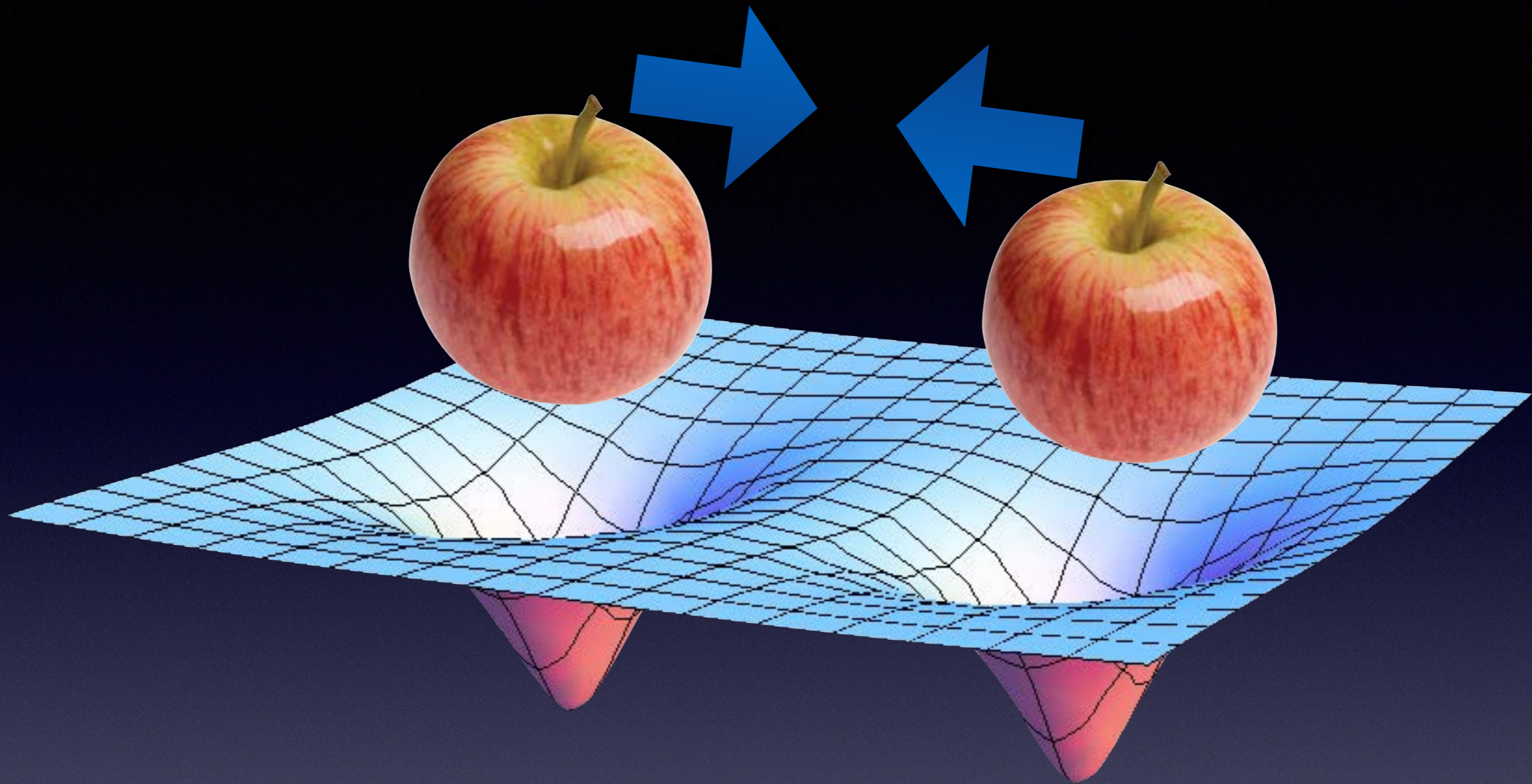
https://commons.wikimedia.org/wiki/File:The_Earth_seen_from_Apollo_17.jpg

<https://apod.nasa.gov/apod/ap130301.html>

Einstein says it's due to the warping
of the spacetime itself.

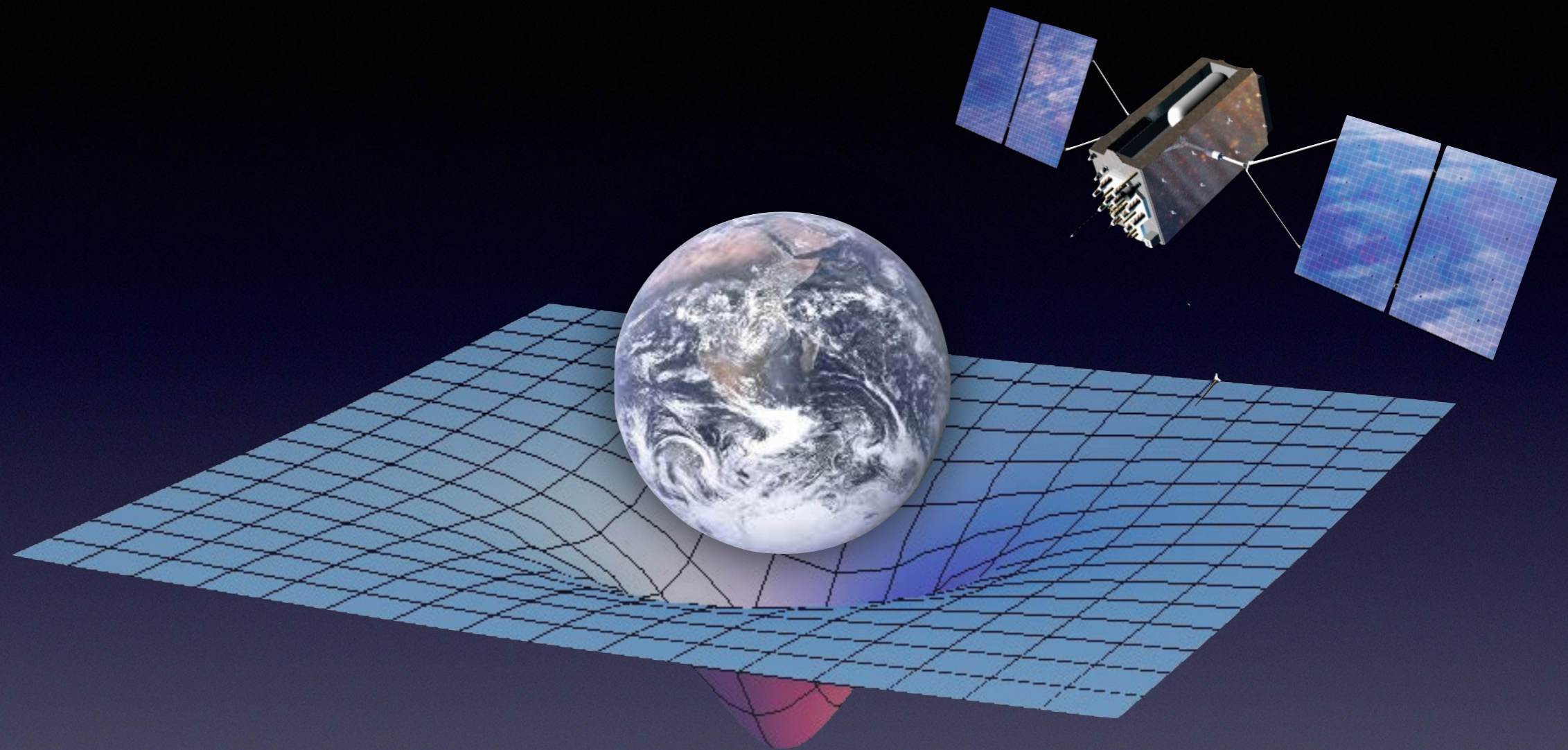


Called General Relativity.



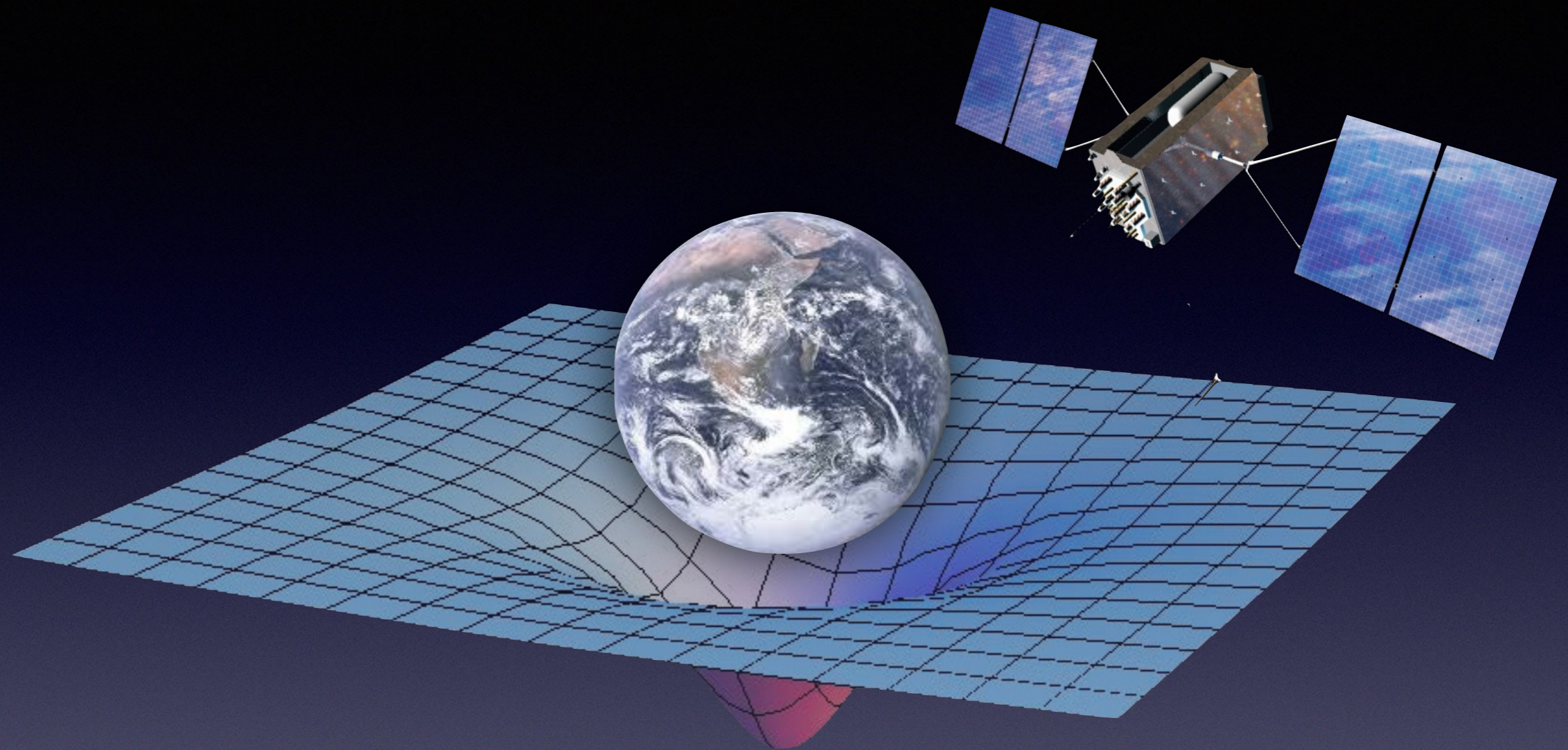
Attraction between apples can also be described by General Relativity if you want, but it's probably overkill.

<https://www.flickr.com/photos/applesnpearsau/12197650876>

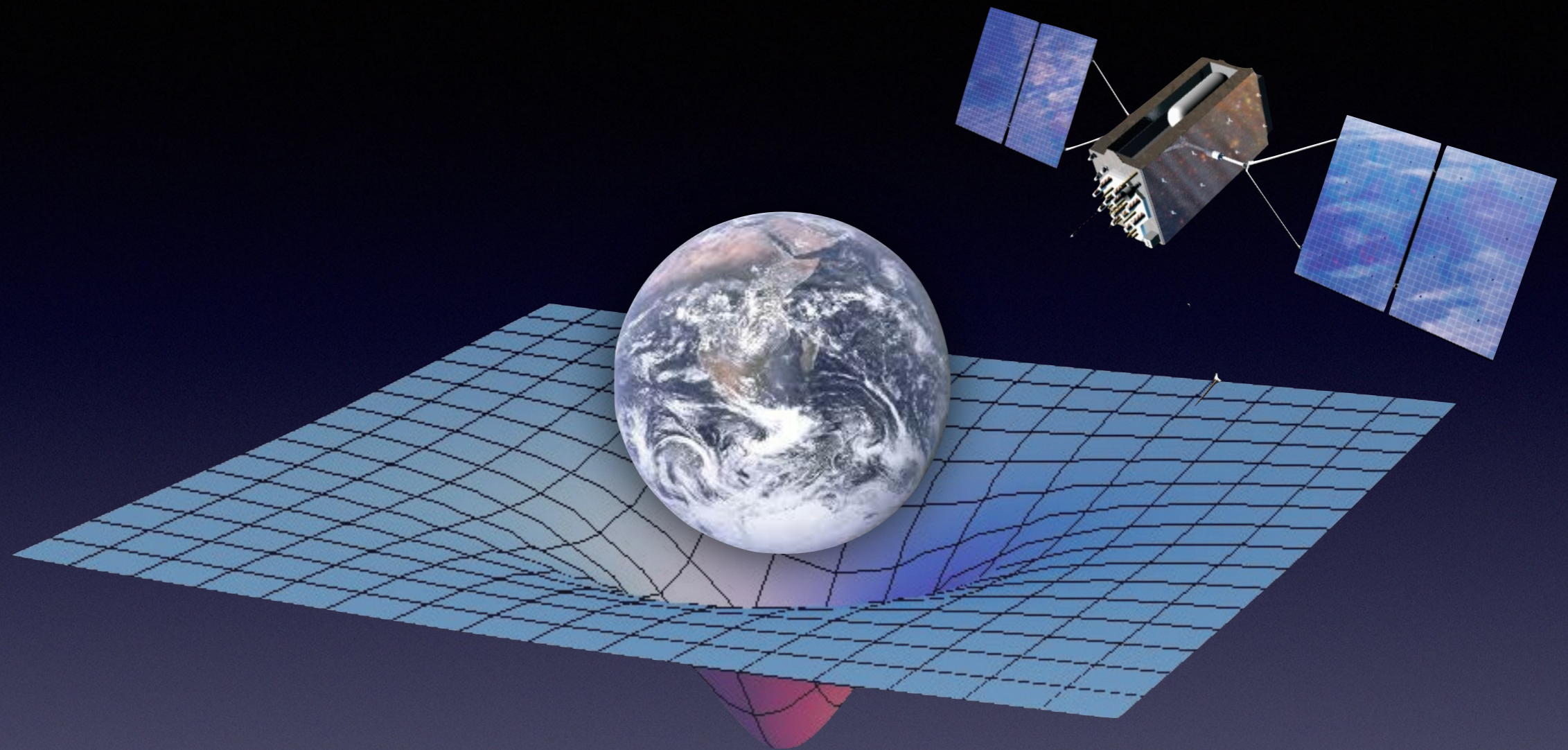


If you have a smartphone, it probably has GPS in it.

Due to relativistic effects,
the time inside the satellite runs faster
(around $40 \mu\text{s}$ per day).

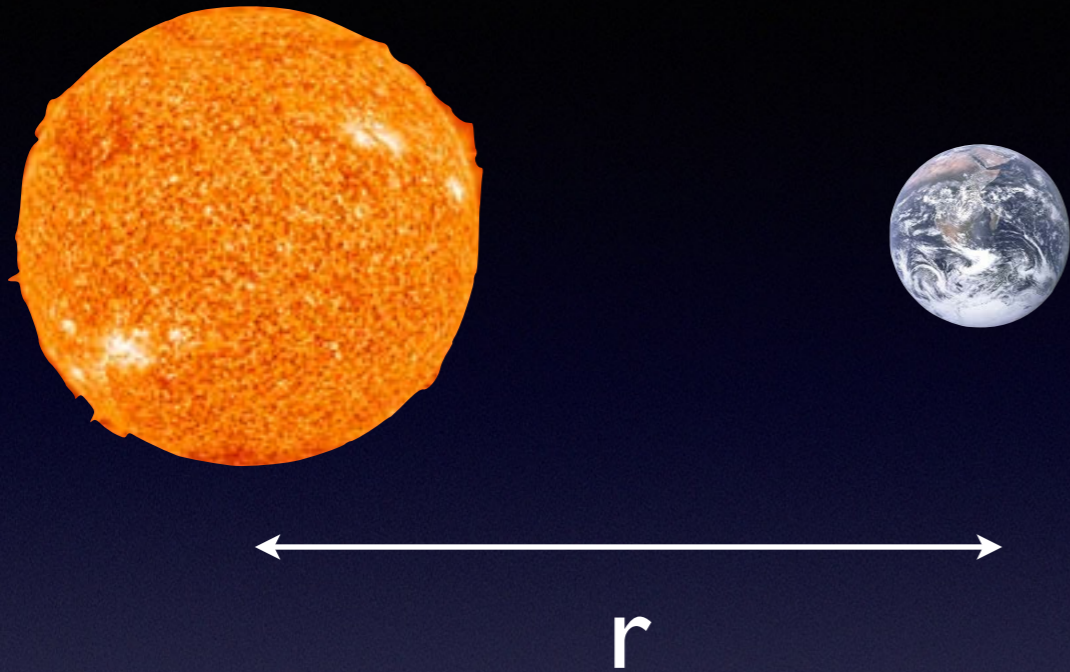


If uncorrected, this would totally ruin the accuracy of your satellite navigation system!
People who designed GPS knew this, and implemented precaution against it.

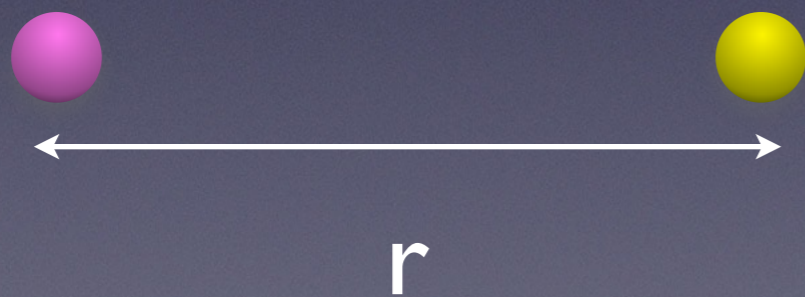


Even without Einstein, we would have known the special and general relativity by now, first as a mysterious source of error in the GPS system.

Gravity

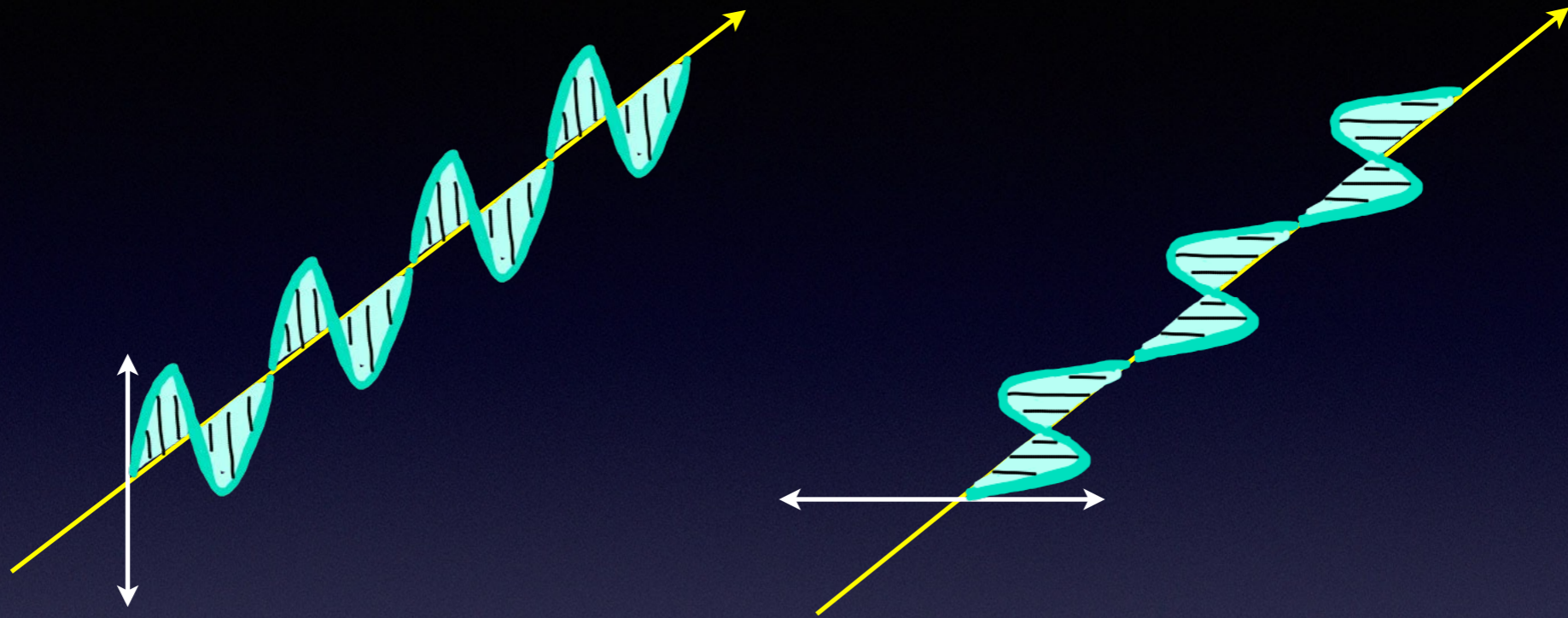


$$F = G \frac{Mm}{r^2}$$



$$F = \frac{1}{4\pi\epsilon_0} \frac{Qq}{r^2}$$

Electromagnetism



Light (electromagnetic wave) has two polarizations.

You rotate one 90 degrees, you get the other.

We can't see polarization of light directly,
but mantis shrimps can.

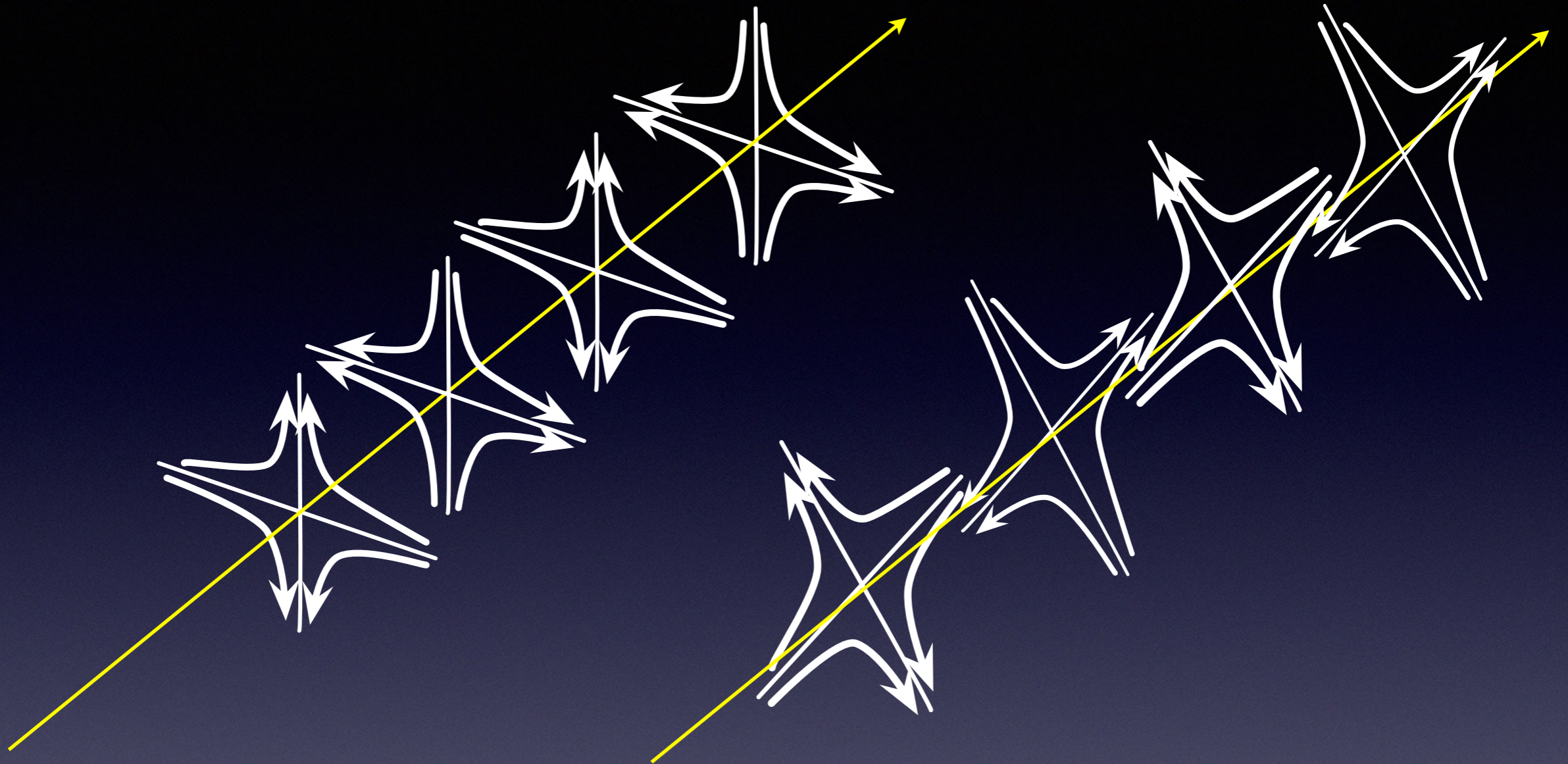


<https://www.flickr.com/photos/37707866@N00/227619703/>

Some sunglasses have polarizers.

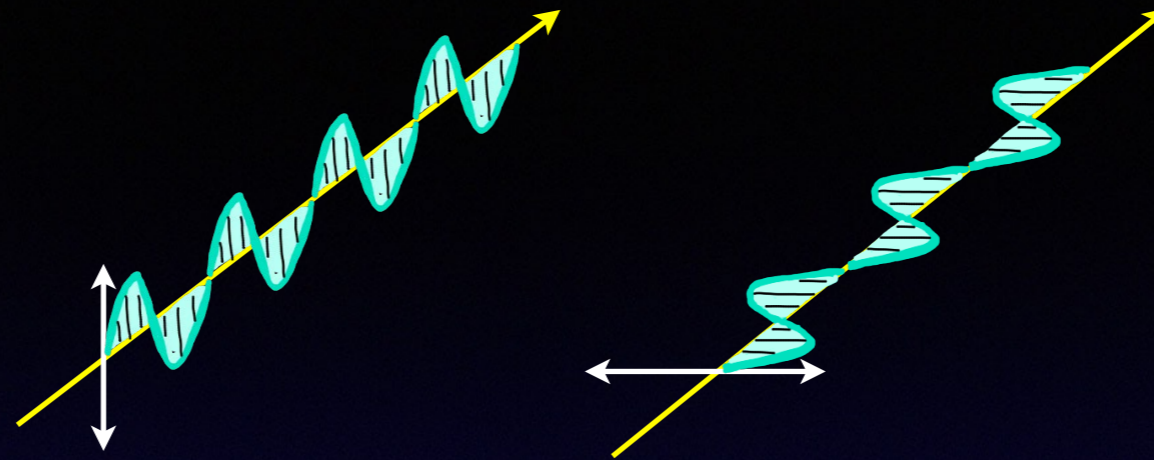


https://commons.wikimedia.org/wiki/File:Circularly_polarized_glasses.jpg

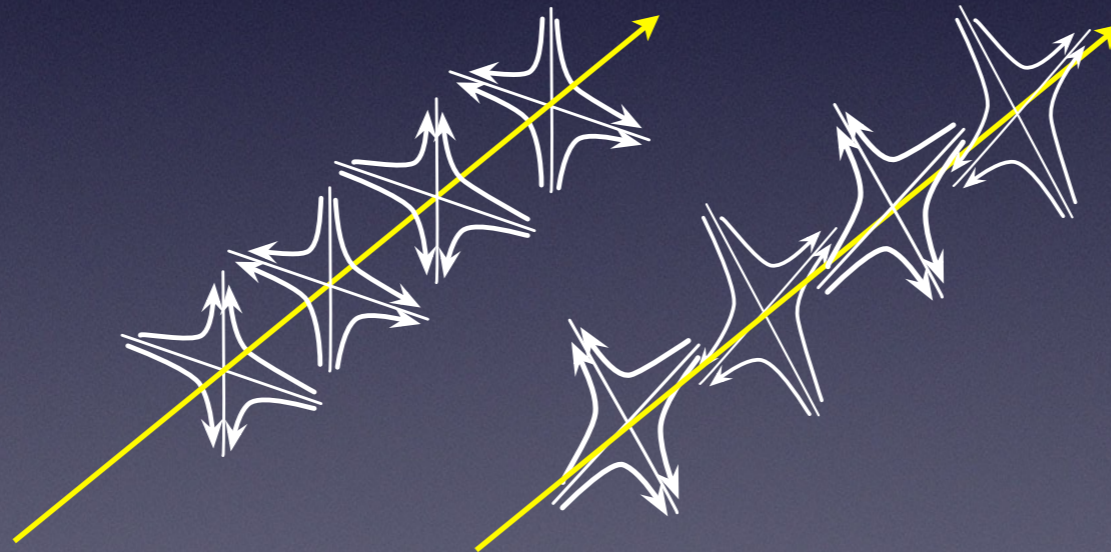


Gravitational wave also has two polarizations.

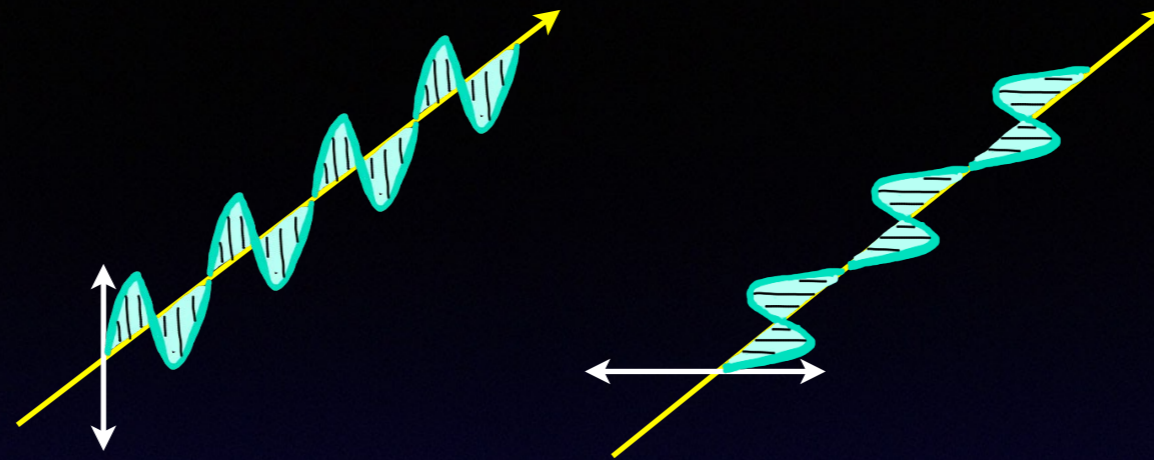
You rotate one 45 degrees, you get the other.



You rotate one **90** degrees, you get the other.
Called Spin 1.



You rotate one **45** degrees, you get the other.
Called Spin 2.



You rotate one **90** degrees, you get the other.

Called Spin 1.

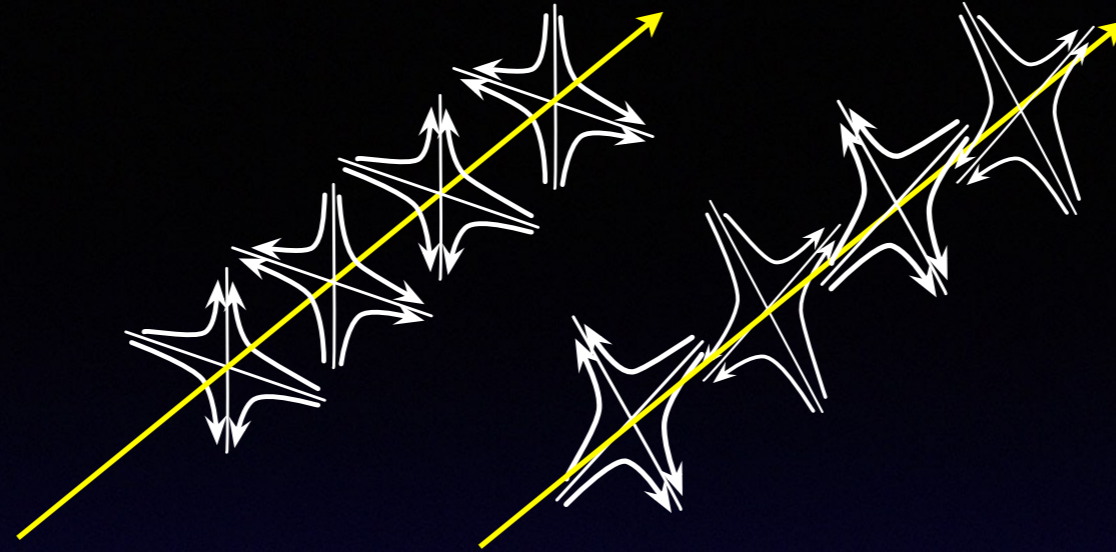
Light (electromagnetism) is spin 1.

“Weak nuclear force” is also spin 1.

“Strong nuclear force” is also spin 1.

Theoretically, you can have as many spin-1 forces
as you want.

Experimentally, there are **three**.



You rotate one **45** degrees, you get the other.
Called Spin 2.

Gravity is spin 2.

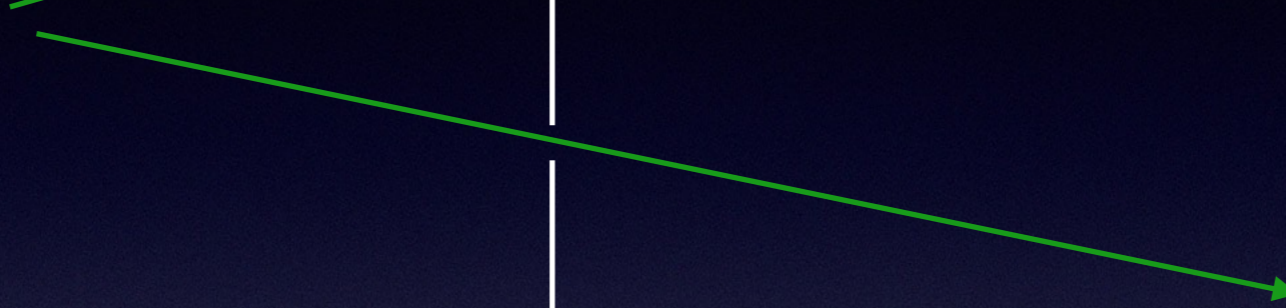
Experimentally, there is only one spin 2 force.

Theoretically, physicists **even don't know how** to
write a theory with more than one spin-2 force.
It's simply impossible.

- There are four forces in the world:
 - Electromagnetism (light) spin 1
 - “Weak nuclear force” spin 1
 - “Strong nuclear force” spin 1
 - Gravity spin 2
- Gravity is rather different !

- ✓ ● What's gravity?
- What's quantum mechanics?
- Why do we have to reconcile them?
- How do we reconcile them?

What's Quantum Mechanics?



Electron
Source

Double
Slits

Screen



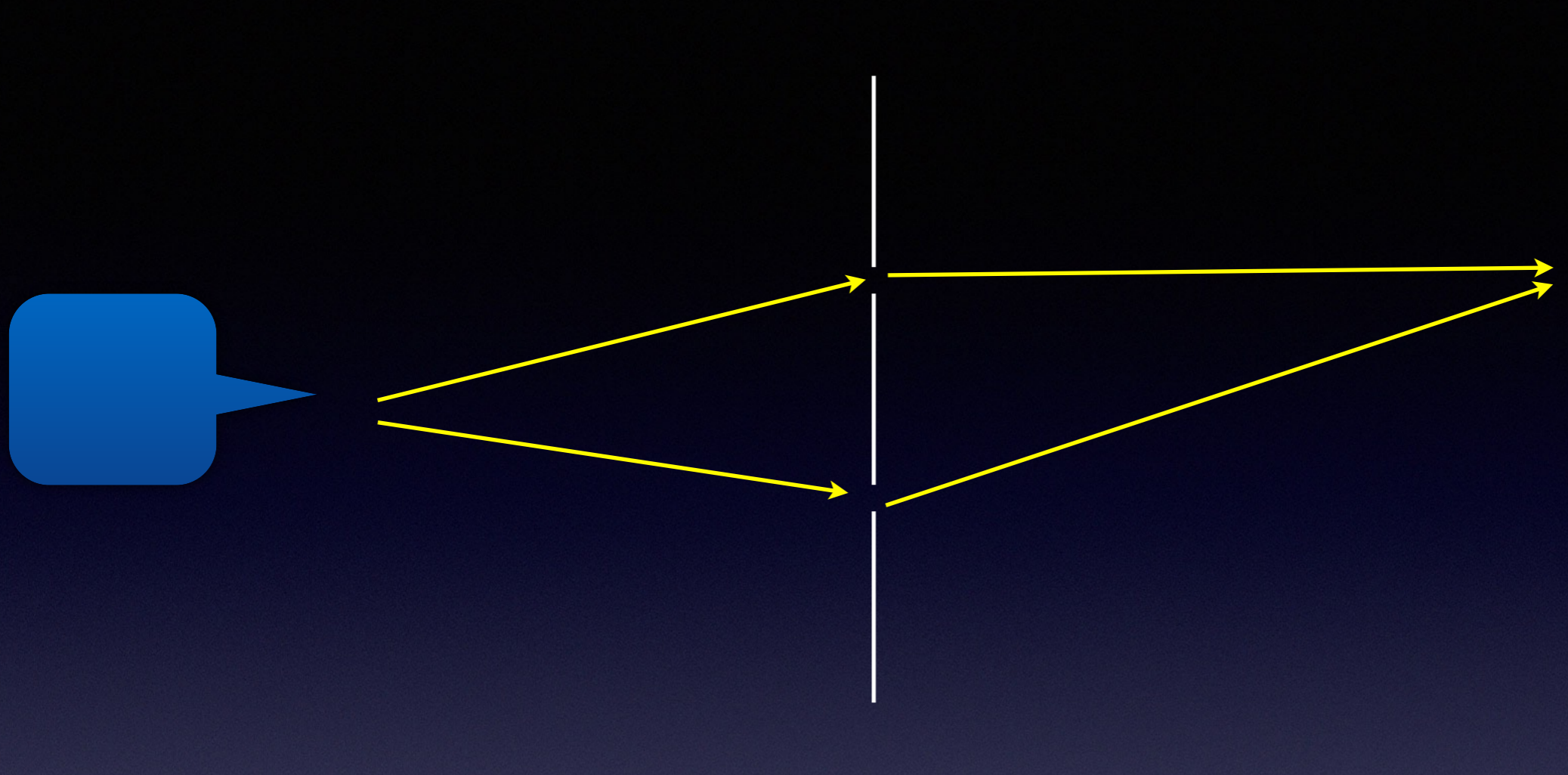
(c) Hitachi / Prof. Tonomura

This used to be available from <https://www.hitachi.com/rd/research/em/movie.html> ,
but alas, no longer. It is now available at https://www.youtube.com/watch?v=_oWRI-LwyC4 (without narration)
and at <https://www.youtube.com/watch?v=jvOOP5-SMxk> (with narration)



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One electron passes the two slits
at the same time...

Its “wavefunction” interfere,
and causes



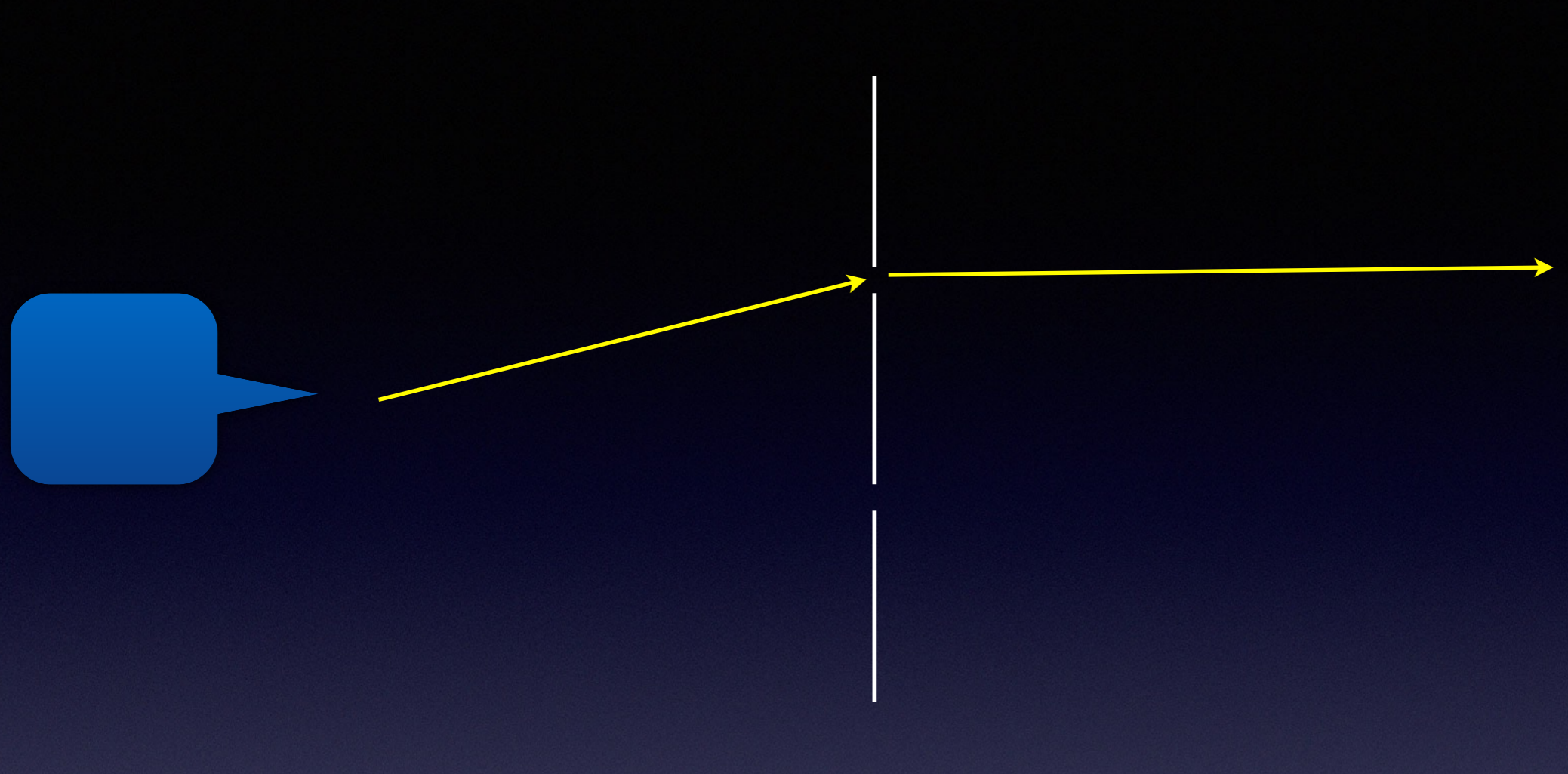
If nobody is watching
the moon,
does the moon exist?

If nobody is watching
the moon,
does the moon exist?

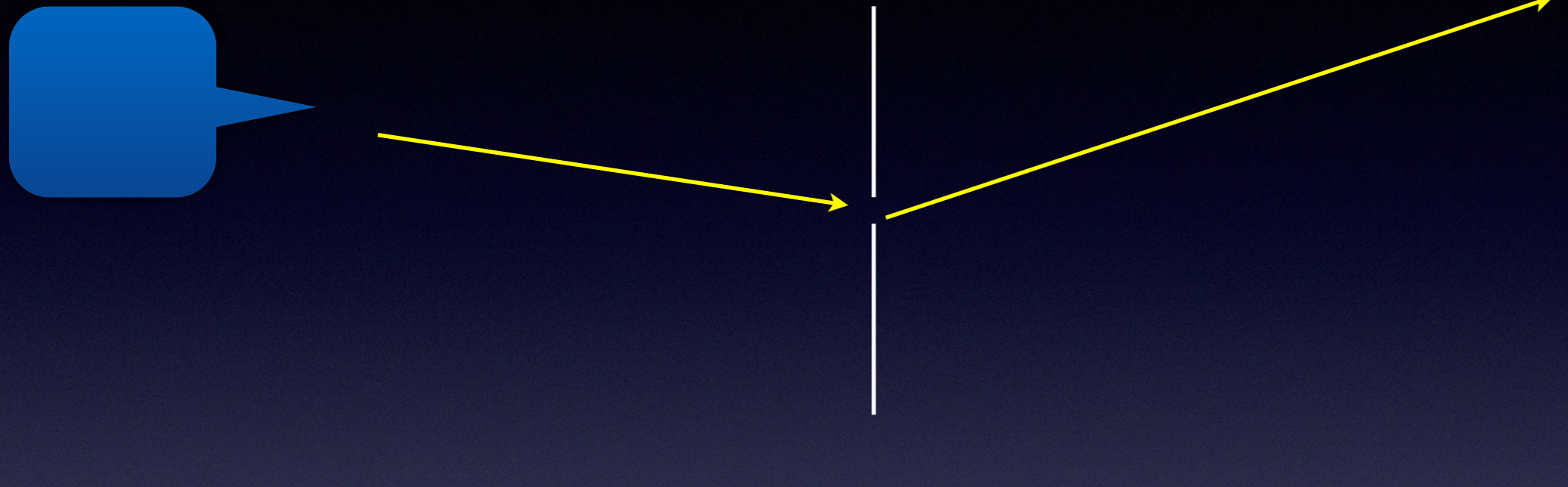
Is it even a physics
question?

If nobody is watching
the moon,
does the moon exist?

Yes it is a physics
question.



If you always watch an electron,
it goes through one particular path.



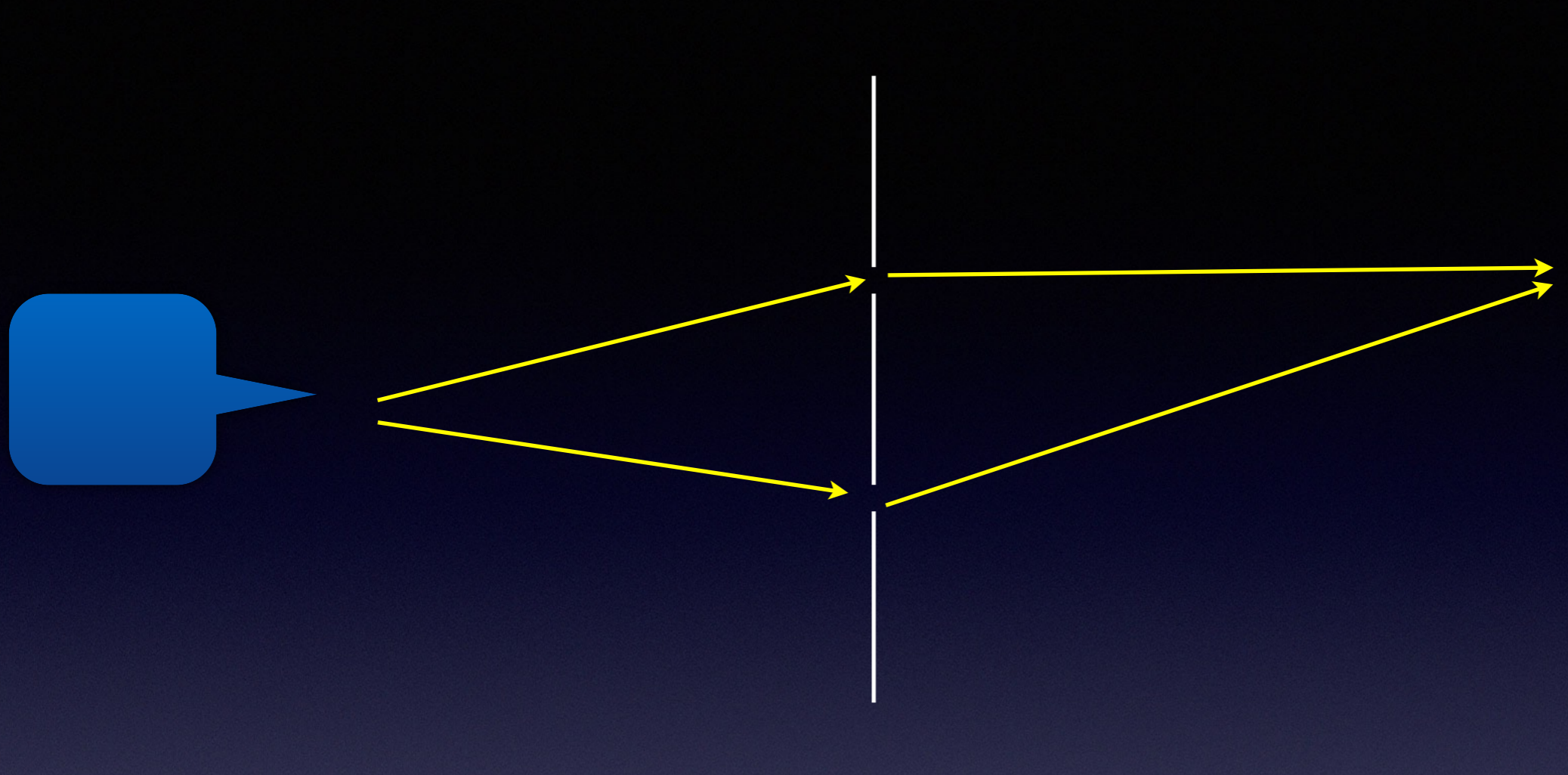
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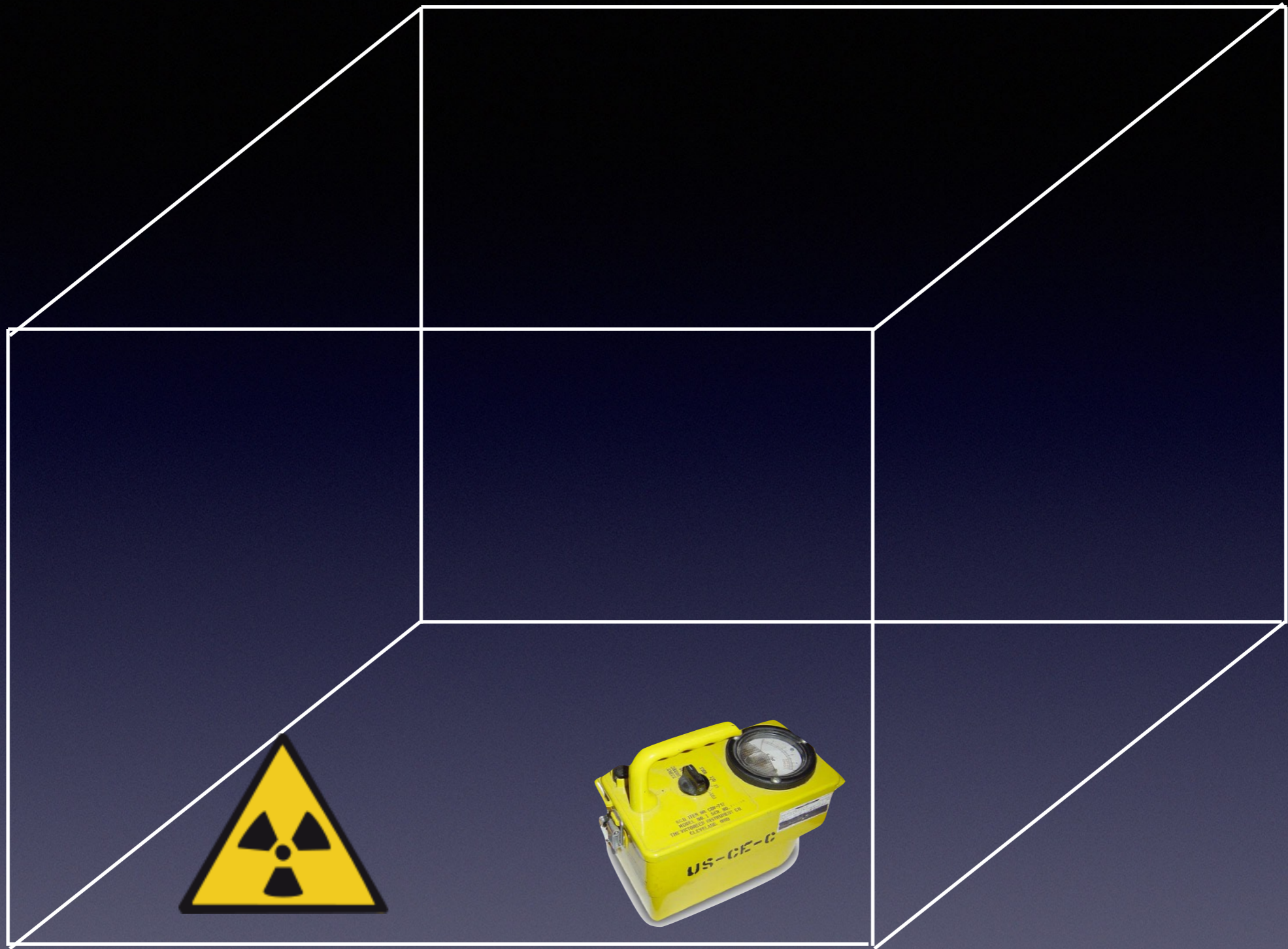
You won't get this.



By *not* watching the electron during the way,
it creates



- Many famous physicists didn't like it.
- But nature doesn't care if famous physicists like it or not.
- For example, consider the "Schrödinger's cat" gedanken experiment.



<https://www.kirin.co.jp/alcohol/beer/ichiban/>

https://commons.wikimedia.org/wiki/File:Danger_radiation.svg

<https://commons.wikimedia.org/wiki/File:Geigerz%C3%A4hler2.jpg>



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“Schrödinger’s me” experiment

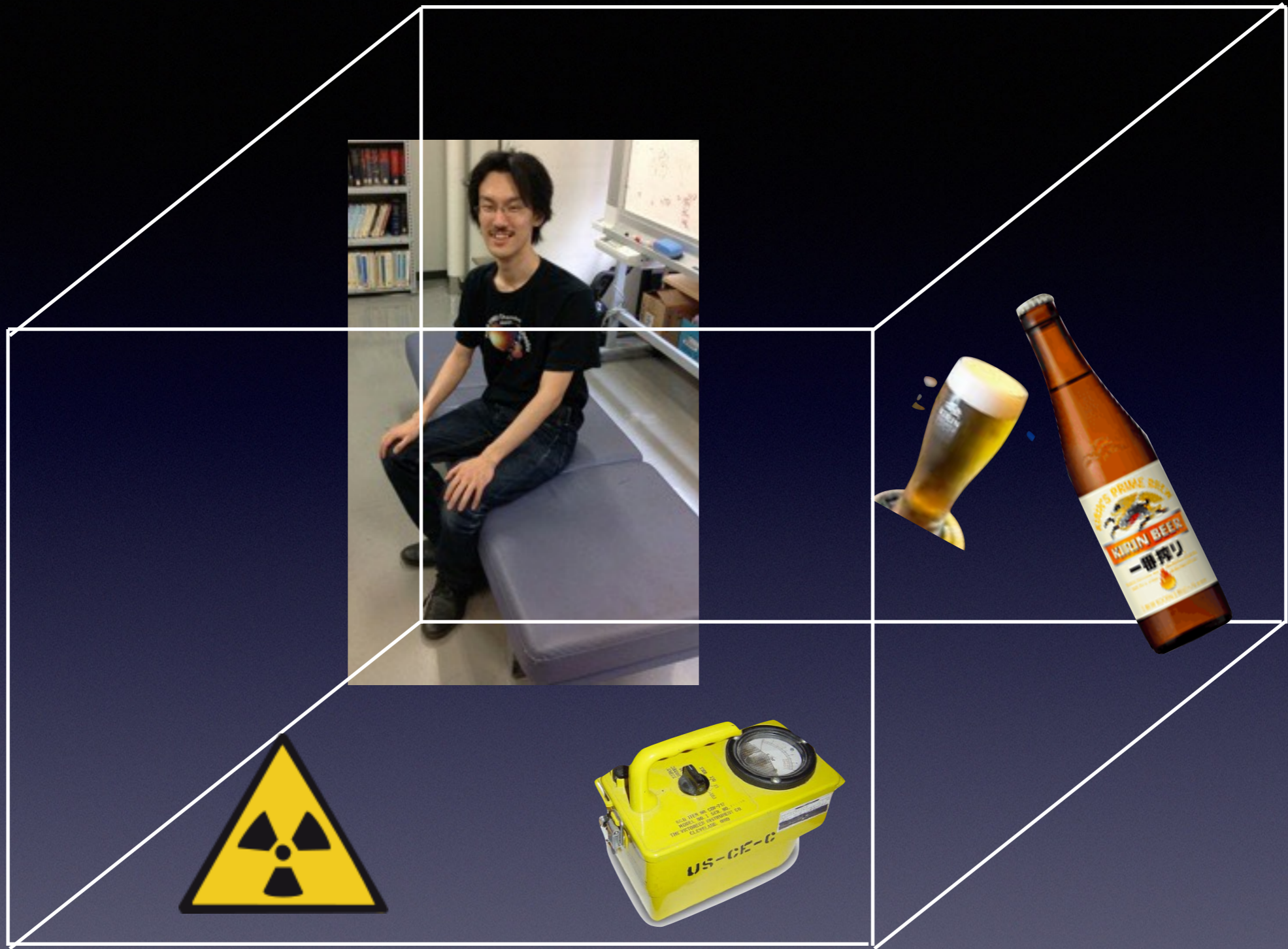
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In an hour, the Geiger counter
“clicks” with 50% probability.



If it clicks, I drink and get drunk.



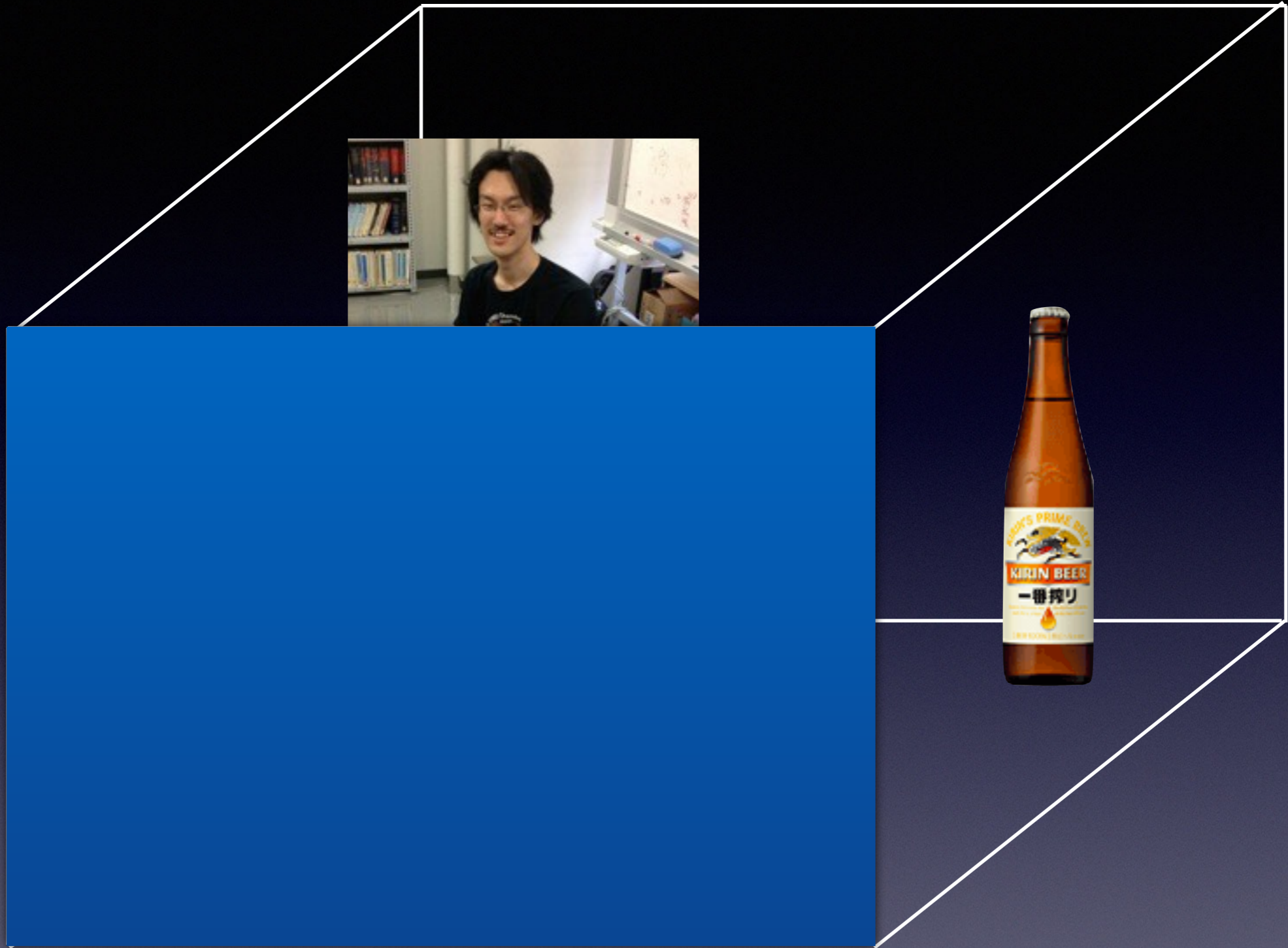
If it clicks, I drink and get drunk.



If it doesn't click,
I don't drink and stay sober.



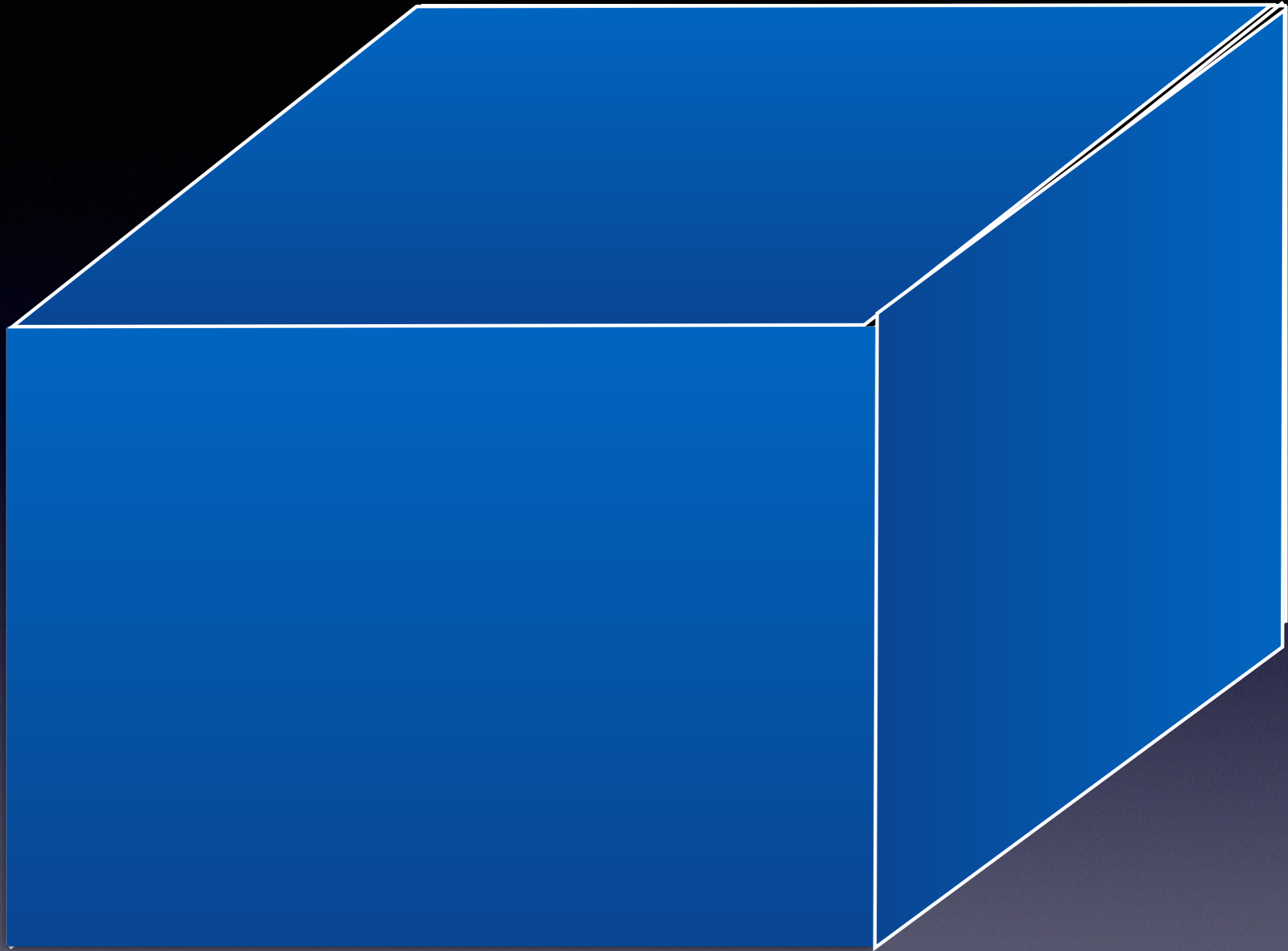
Suppose you keep me in a sealed box
and do this experiment.



Suppose you keep me in a sealed box
and do this experiment.



Suppose you keep me in a sealed box
and do this experiment.



Suppose you keep me in a sealed box
and do this experiment.



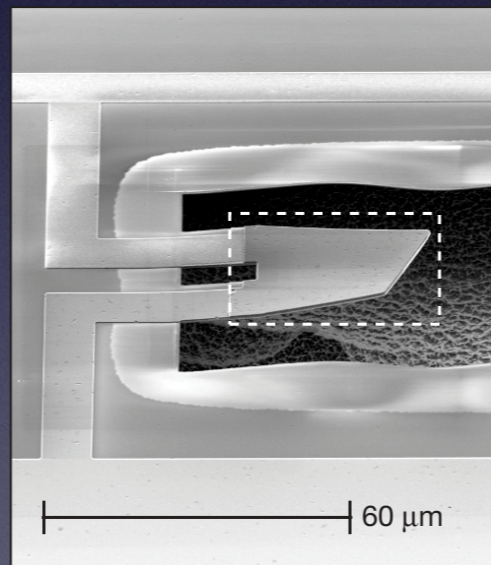
Before you open the box after an hour,
am I in a superposition?



I think I will be, from your point of view
from outside of the box.

Bigger and bigger things are put into
quantum mechanical superposition
experimentally.

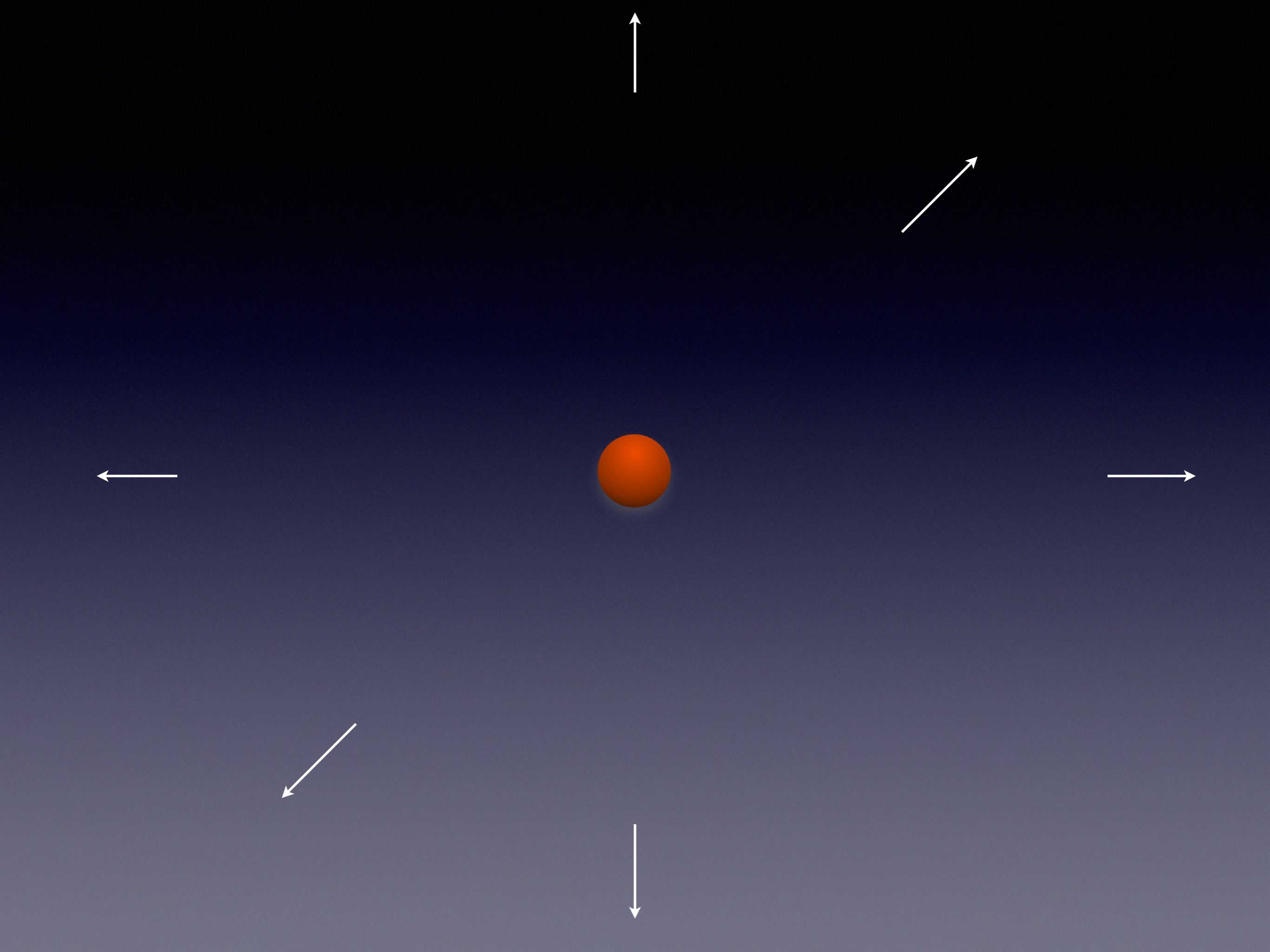
There doesn't seem to be any upper bound
in principle.

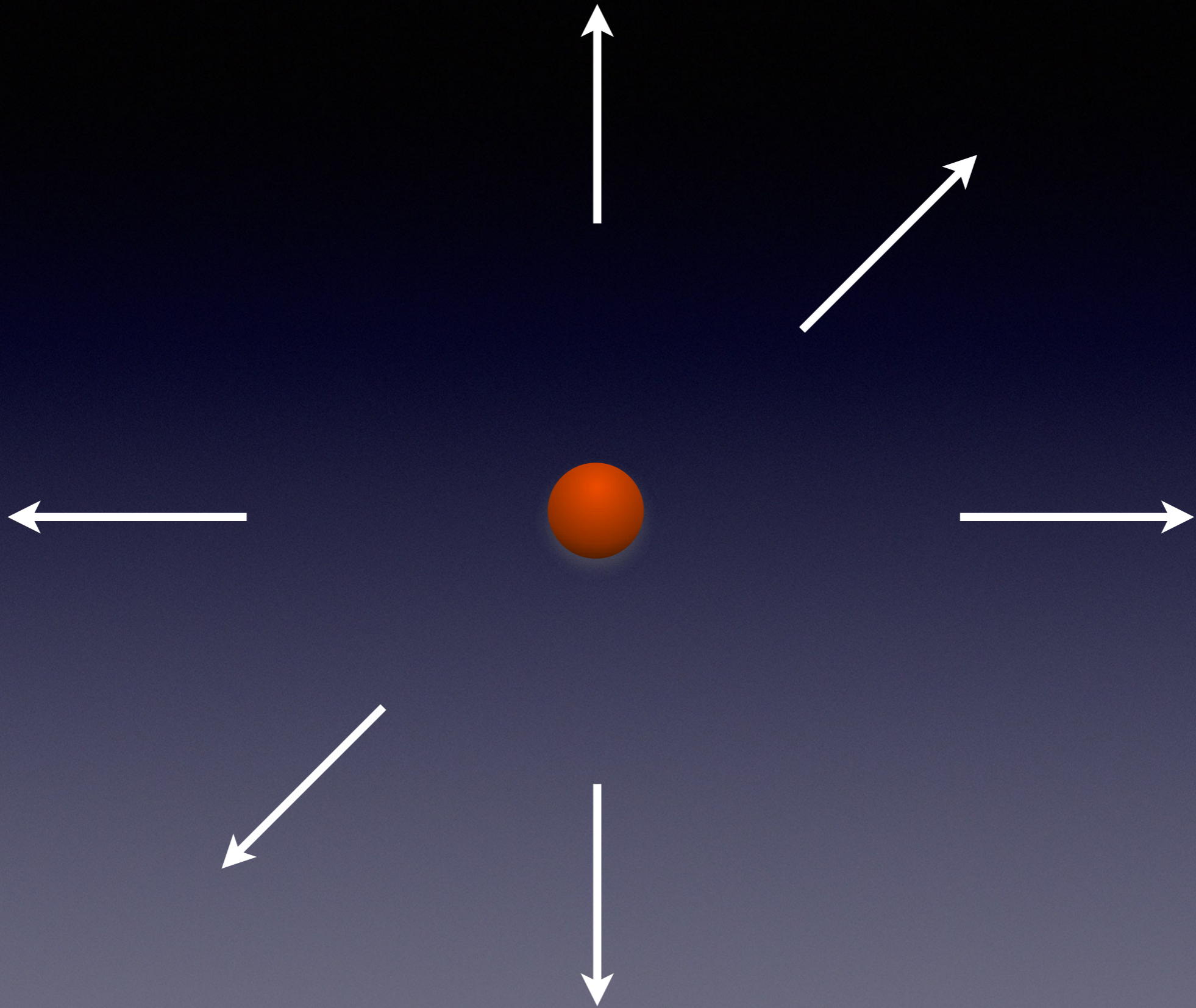


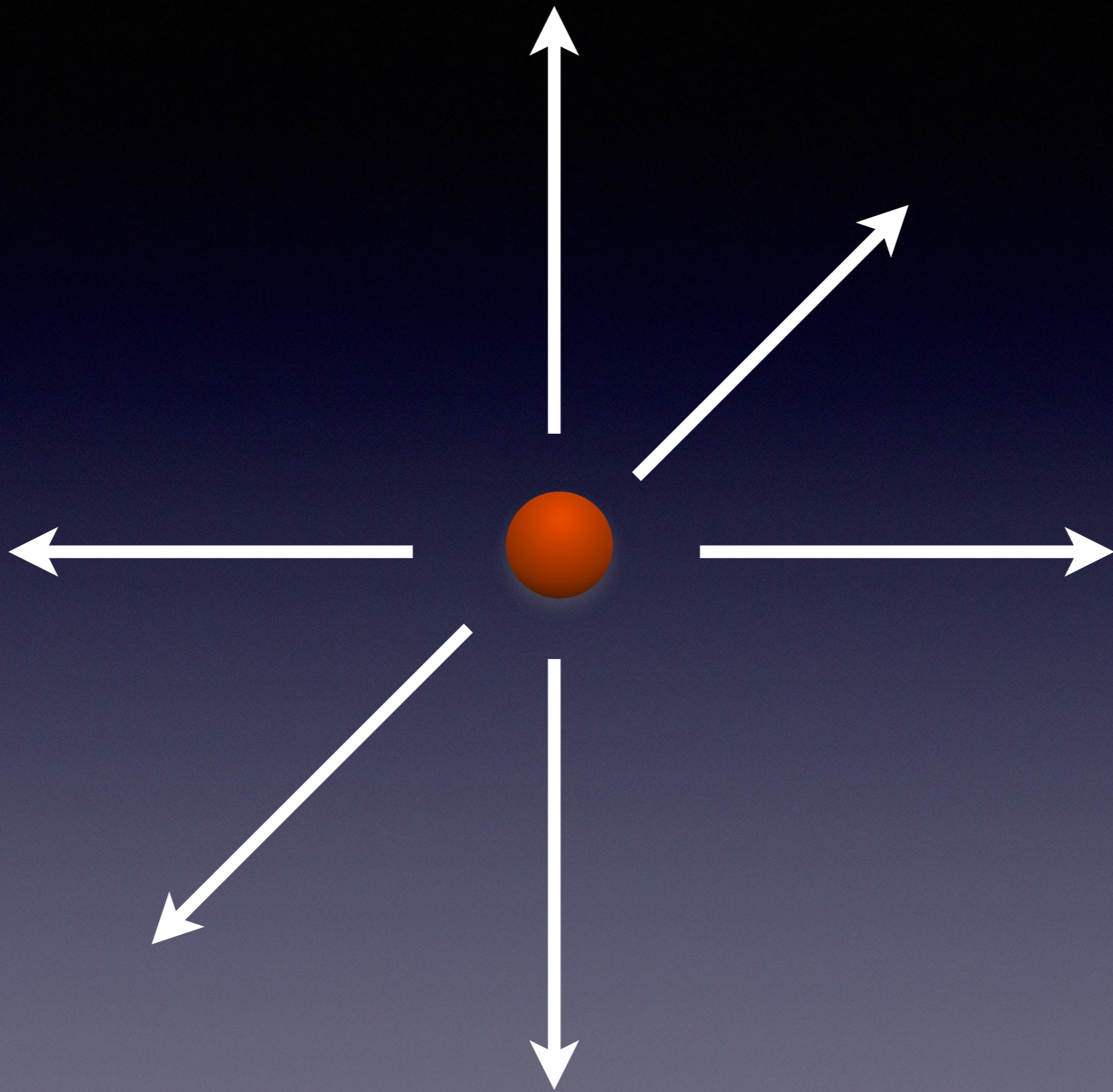
O'Connell et al., Nature 464 (2010) p. 697

- ✓ ● What's gravity?
- ✓ ● What's quantum mechanics?
 - Why do we have to reconcile them?
 - How do we reconcile them?

Why do we have to
reconcile them?







- Electric field $\sim 1/r^2$
- Energy per volume $\sim |\text{electric field}|^2$
- Energy carried by the electric field \sim

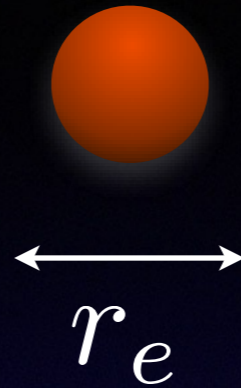
$$\int_0^{\infty} \left(\frac{1}{r^2}\right)^2 r^2 dr = \left[-\frac{1}{r}\right]_{r=0}^{r=\infty} = \infty$$

- An electron, if pointlike, always carry infinite amount of energy.
- $\text{Energy} = \text{mass} \times (\text{speed of light})^2$
- Electron is infinitely massive!
- Of course the electron has finite mass.

- This puzzled physicists at the turn of 20th century greatly.
- One idea which didn't work:

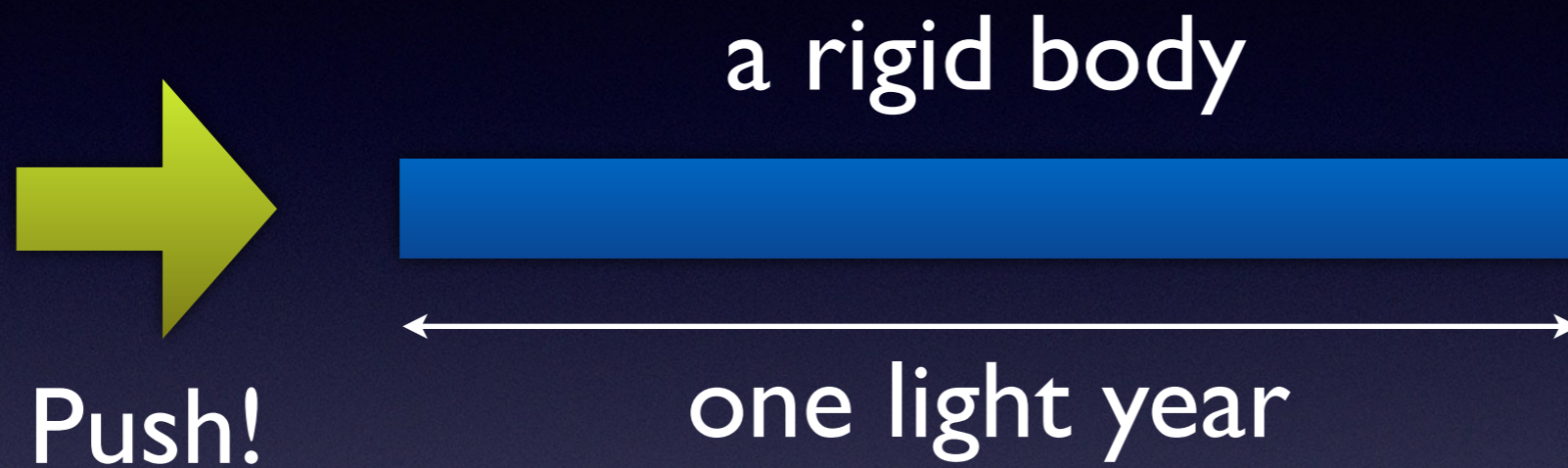
$$\int_0^{\infty} \left(\frac{1}{r^2}\right)^2 r^2 dr = \left[-\frac{1}{r}\right]_{r=r_e}^{r=\infty} = m_e$$

- Maybe all the mass is due to the electric field.
- Maybe electron has a finite radius.



- But it doesn't work with relativity.
- Basically, relativity doesn't like finite-sized rigid body.

- In relativity, nothing can exceed the speed of light.



- This can't happen.
- Finite size = bad in relativity.

- In relativity, nothing can exceed the speed of light.



- This can't happen.
- Finite size = bad in relativity.

- This electron mass problem was solved around in 1950.
- So it took almost half a century to solve.
- I can't easily say how it was resolved... as it is rather involved.
- It uses Quantum Mechanics in an essential way.

Naively, we expect something like

Real Electron Mass =

$-\infty$

“Naked Electron Mass”

+

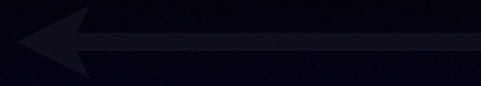
Energy of the Electric Field

$\infty + m_e$

But you never see a naked electron
without its electric field.

So you don't and can't think about them.

Naively, we expect something like



Real Electron Mass

But you never see a naked electron
without its electric field.

So you don't and can't think about them.

- This theory is called the Quantum Electrodynamics.
- It works extremely well.
- The most amazing example: the electron anomalous magnetic moment

Experiment: 0.00115965218...

Theory: 0.00115965218...

They agree up to the expected experimental & theoretical errors.

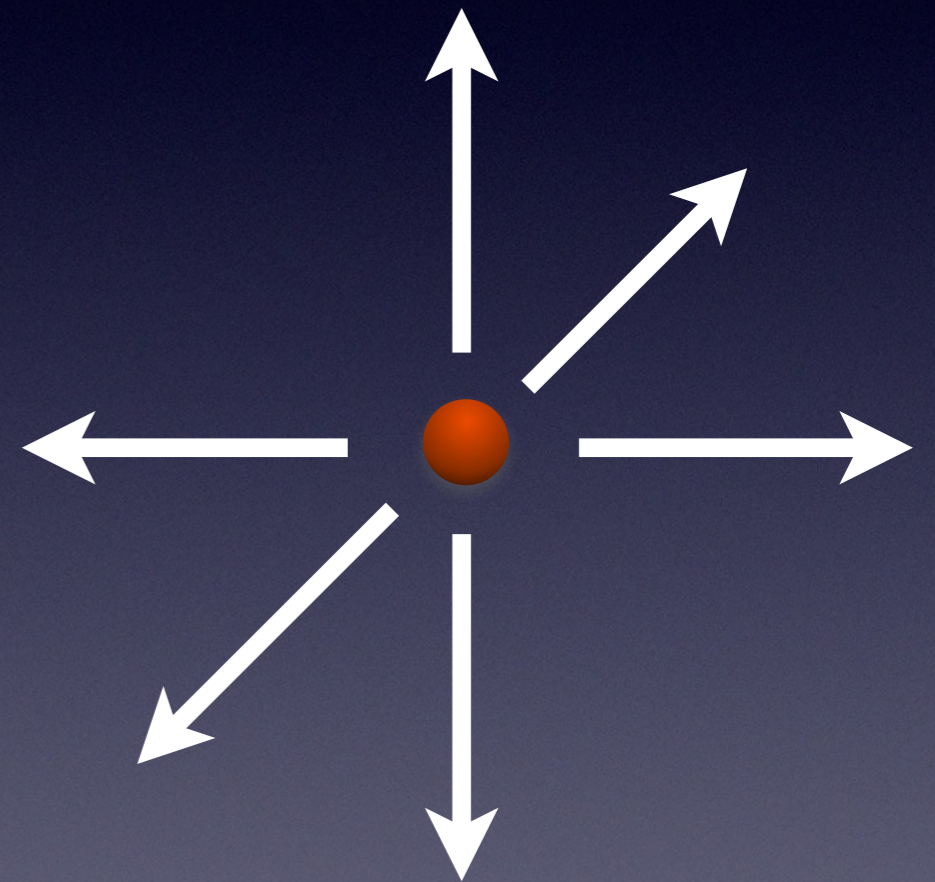
The same problem of
infinite energy arises
for all four forces:

electromagnetism

“strong nuclear force”

“weak nuclear force”

gravity



The same problem of infinite energy arises for all four forces:

electromagnetism

“strong nuclear force”

“weak nuclear force”

Problems solved.

gravity

Problems unsolved.

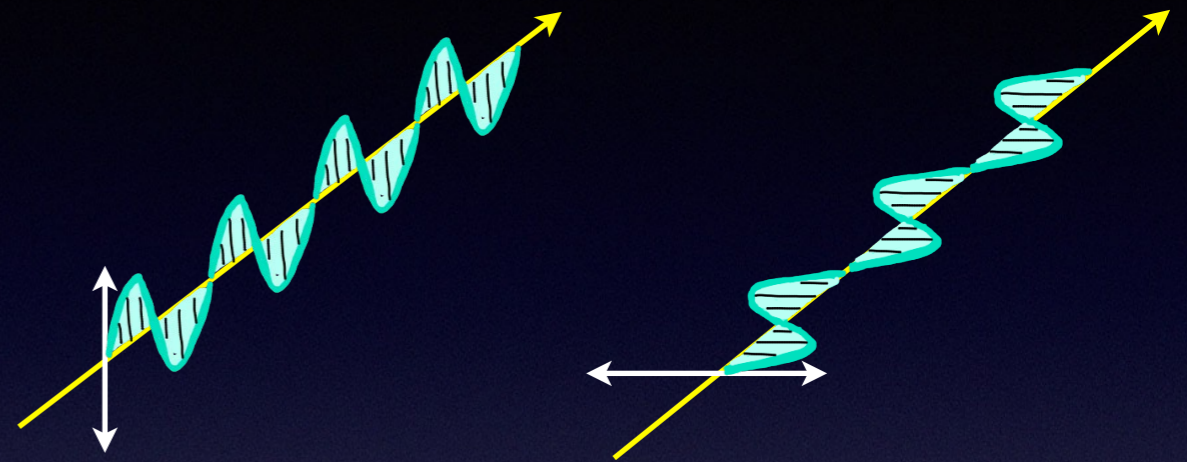
electromagnetism

“strong nuclear force”

“weak nuclear force”

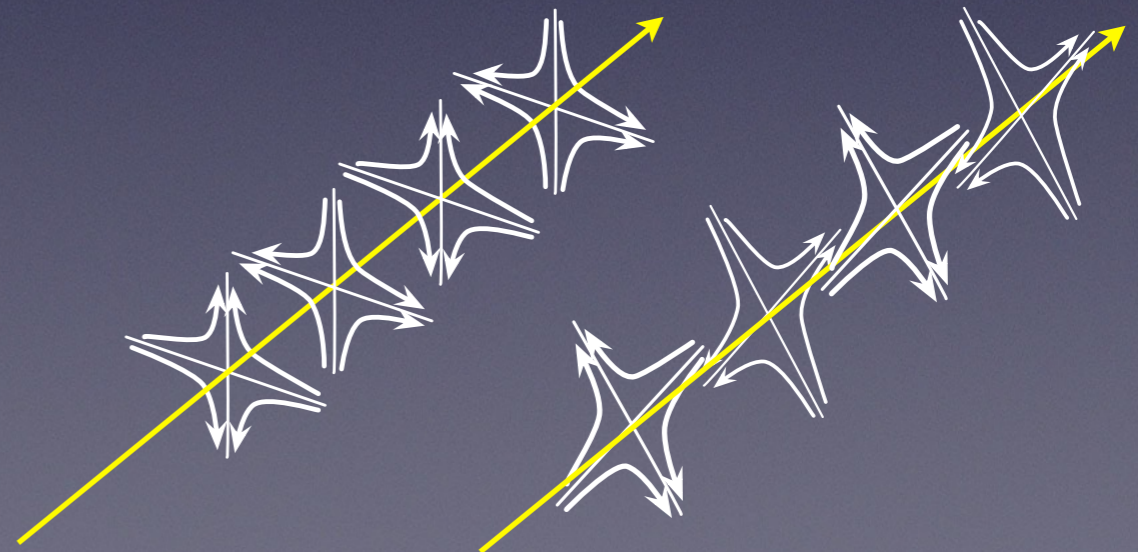
gravity

Problems solved.



Called Spin 1.

Problem unsolved.



Called Spin 2.

Gravity is different.

- Anyway, we learned by the late 70s how to treat quantum mechanically
 - electromagnetism,
 - “strong nuclear force,” and
 - “weak nuclear force.”
- So it was unsatisfactory that we didn’t know how to treat **gravity** quantum mechanically.

- ✓ ● What's gravity?
- ✓ ● What's quantum mechanics?
- ✓ ● Why do we have to reconcile them?
 - How do we reconcile them?

How do we
reconcile them?

- So far I told you
 - The world is quantum mechanical.
 - There is gravity in the world.
- So we want to treat gravity quantum mechanically.

There are two known methods:

Loop Quantum Gravity

String Theory

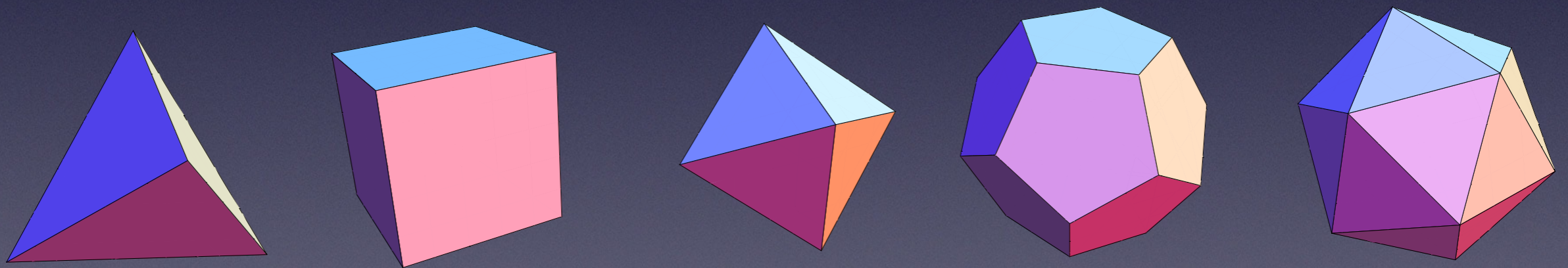
Which is correct? Nobody knows yet.

This is because the quantum mechanical effect of gravity tends to be **very, very tiny** and very, very hard to observe.

- A theory is correct if it describes some aspect of this world we live in.
- Neither string theory nor loop quantum gravity is known to be correct in this sense.
- At least both are “logically consistent.”

- So, I'm studying a logically consistent entity, called String Theory.
- I'm doing it mostly disregarding whether it describes the world or not. The structure of the theory itself is interesting to me.
- This makes me a non-scientist.

- Mathematicians deal with “logically consistent idealized entities” rigorously.
- For example, ancient Greeks have found that there are five and only five regular polyhedra:



- This is the last proposition of Euclid’s *Elements*!

- Unfortunately, string theory is not quite rigorous yet.
- So mathematicians don't consider string theorists mathematicians.
- Scientists don't consider string theorists scientists either.
- So I'm stuck.

What's String Theory?

- It was not invented to treat gravity quantum mechanically.
- Instead, it came from the idea of a few crazy physicists:

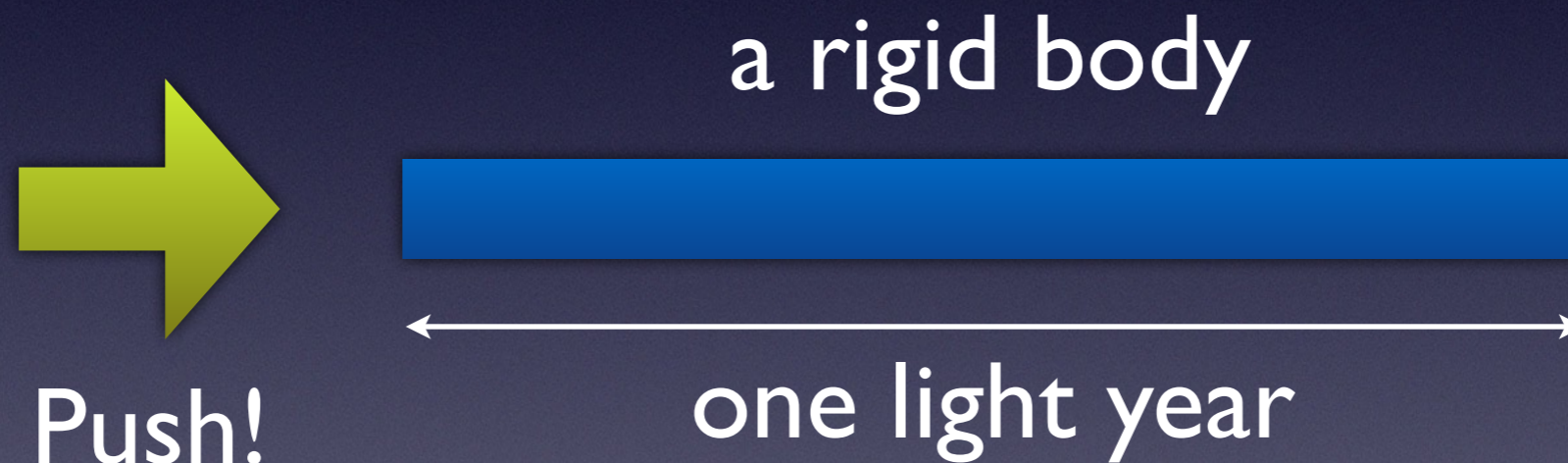
They thought, around early 1970s,
“It’s too boring to always treat
zero-sized particles quantum mechanically.”



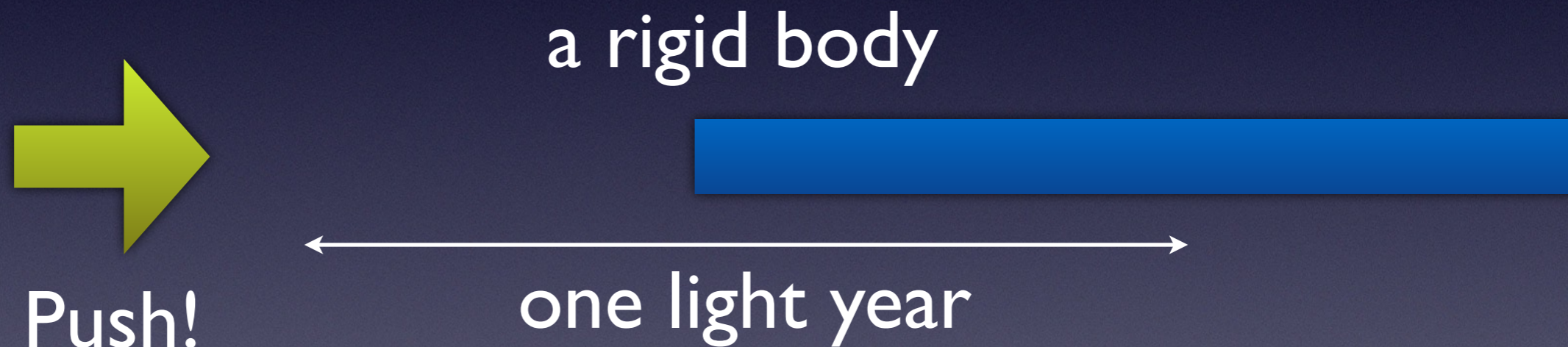
particle	zero size
string	finite size

What happens if we treat
finite-sized strings quantum mechanically?”

- As I told you, finite sized objects are bad in relativity.



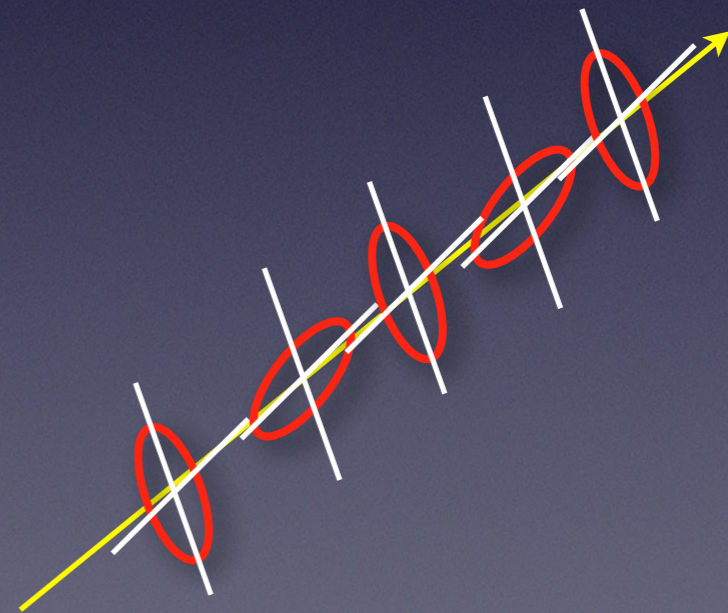
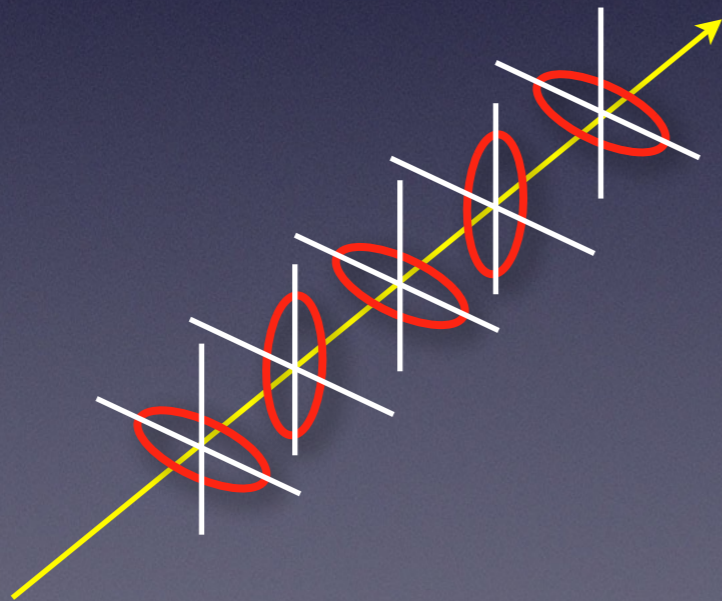
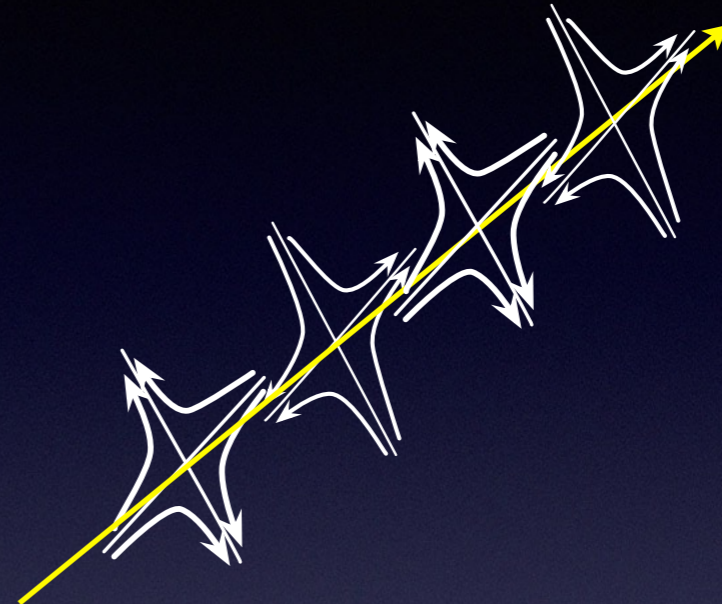
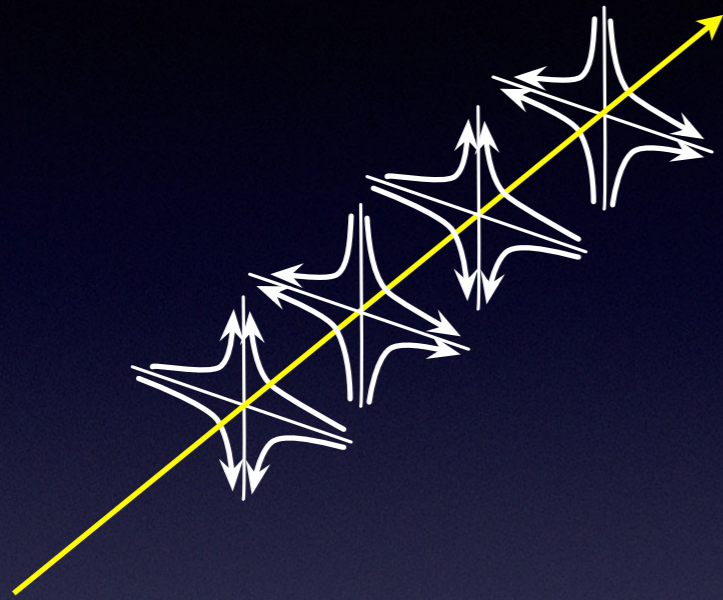
- As I told you, finite sized objects are bad in relativity.



- So, those physicists tried hard to treat strings quantum mechanically,
- but they failed and failed. And then failed.

- They only succeeded in 1984, with a bad news and a good news.
- The BAD: Strings need to move in $9+1$ dimensional spacetime.
- The GOOD:
It contained quantum gravity.

- Let's start with the good news.



- Strings can vibrate just as gravitational waves would.

- The bad news: $9+1$ dimensions?



$3+1$ dimensions !



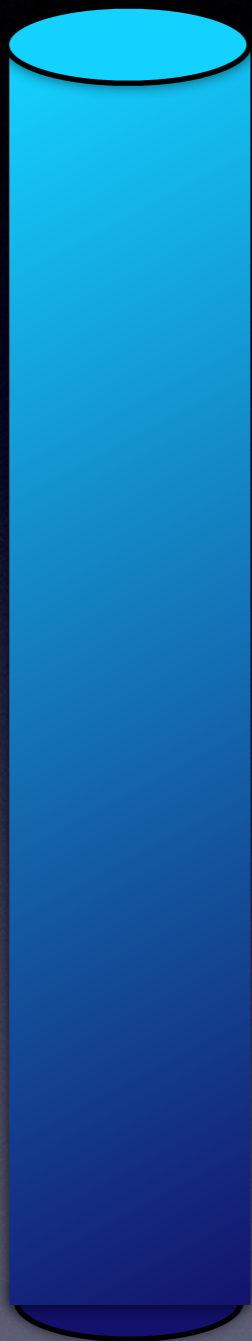
1 dimension ?



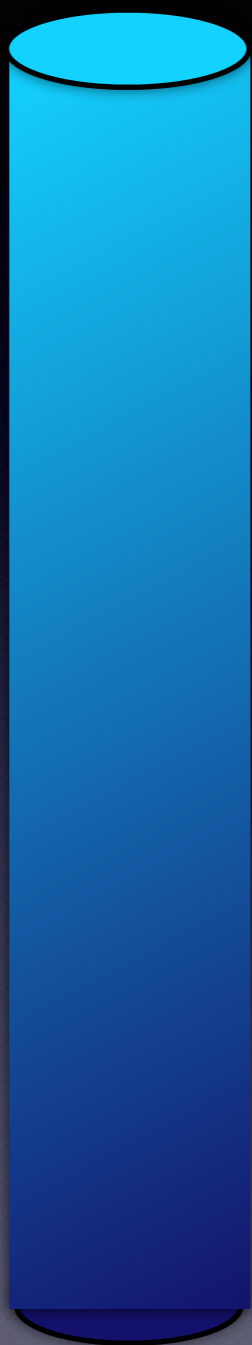
1 dimension ?



1 dimension ?



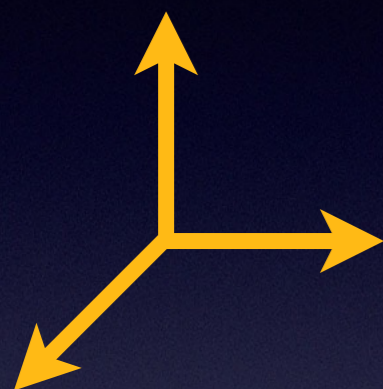
1 dimension ?



1 dimension ?



Another dimension !



Space



Time

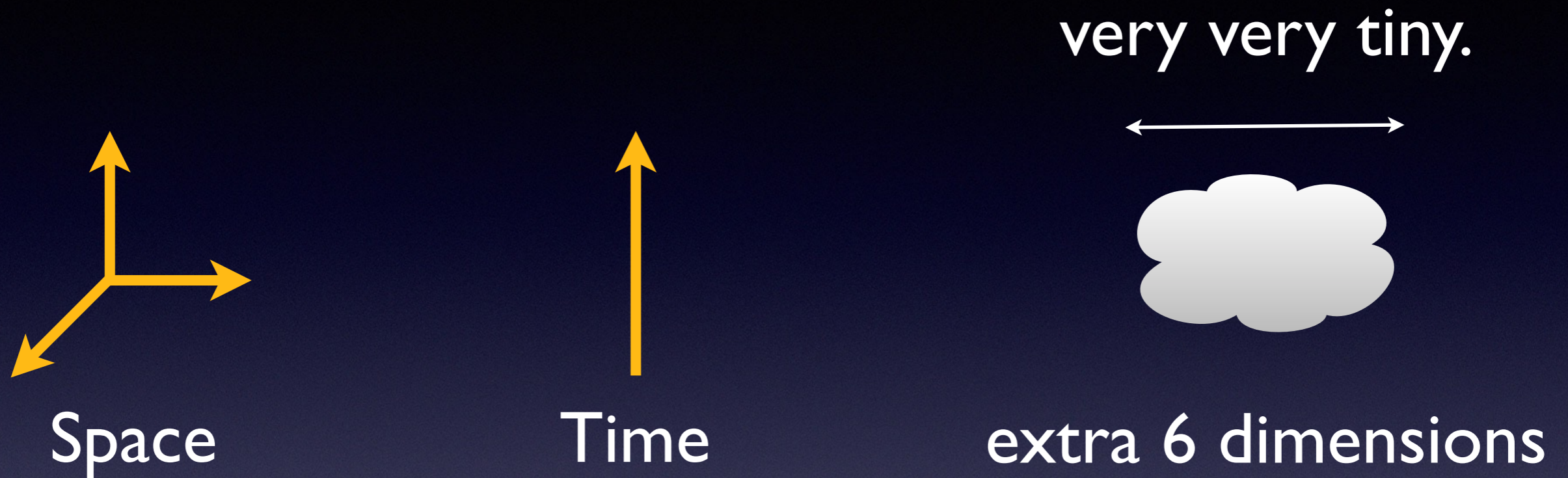
3+1 dimensions

needs to be
very very tiny.

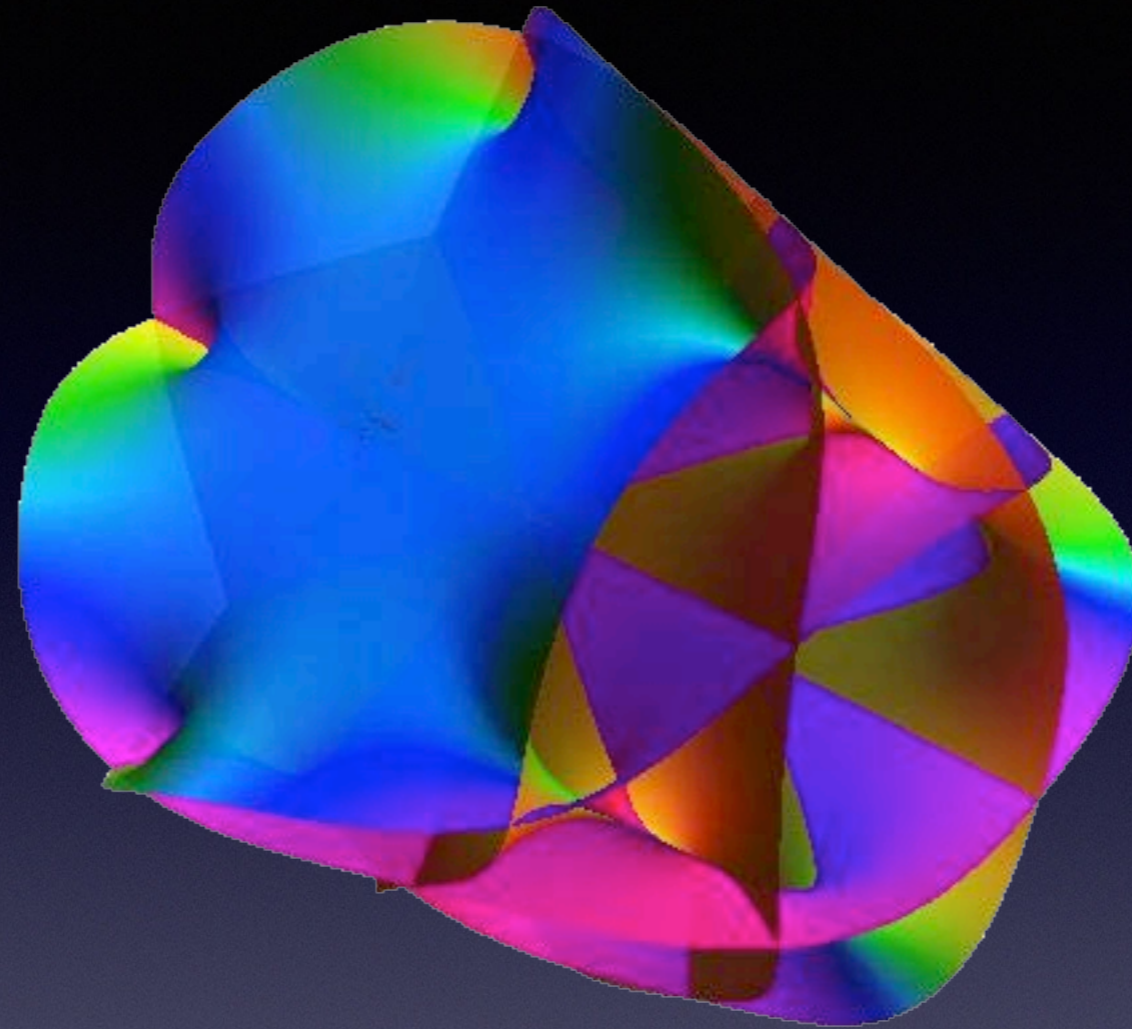


extra 6 dimensions

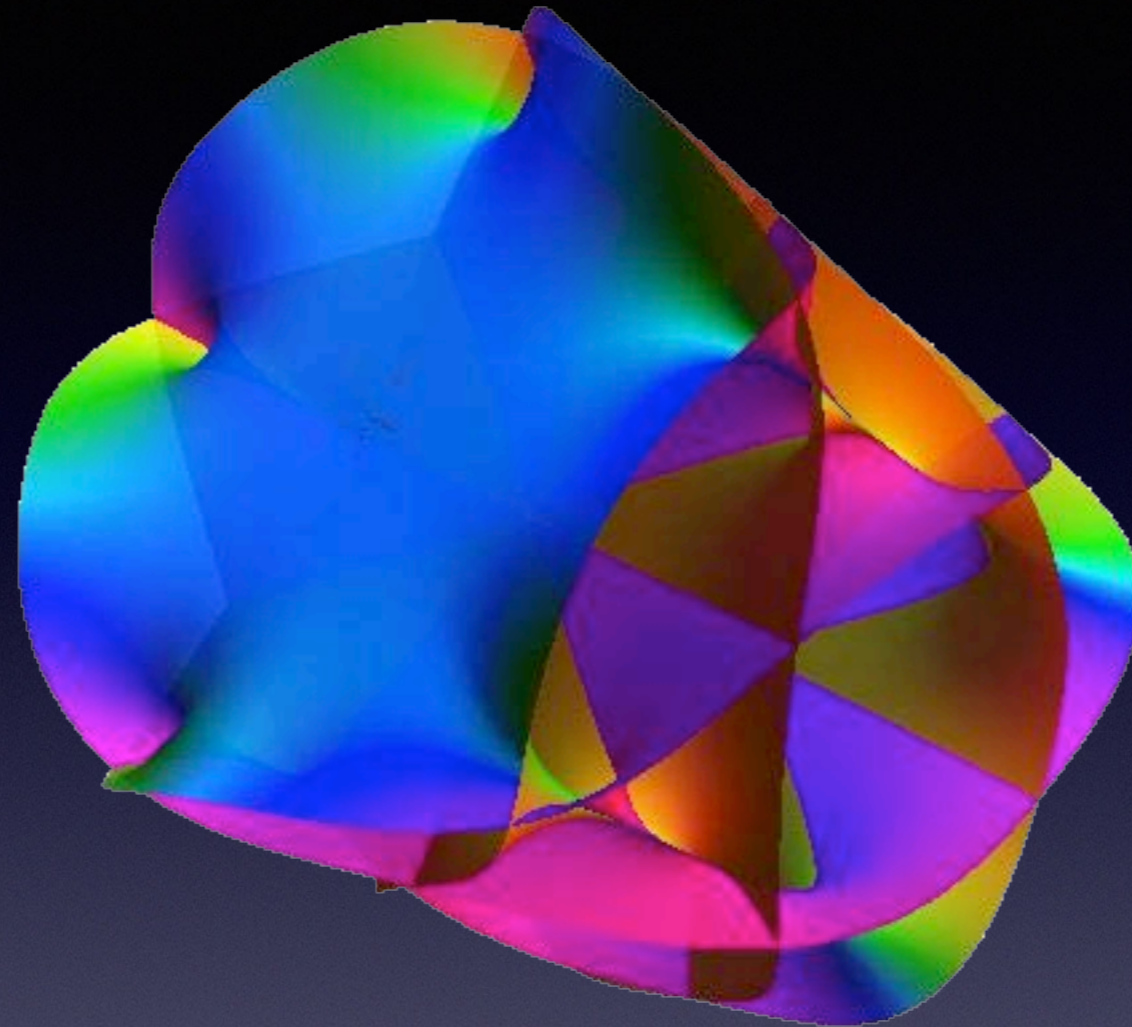
- If the real world is really like this,



- The shape of the extra 6 dimensions determine the physics of elementary particles.
- E.g. how many kinds of electron-like particle there is.



- This shows 2d slices of very-well studied six-dimensional space called the quintic Calabi-Yau...



- This shows 2d slices of very-well studied six-dimensional space called the quintic Calabi-Yau...

9+1 dimensional world is described by String Theory

The extra 6d space has this particular shape:



(specified by a math equation.)



The 3+1d physics is such and such.

If this agrees with experiments, claim victory!

9+1 dimensional world is described by String Theory

The extra 6d space has this particular shape:



(specified by a math equation.)



The 3+1d physics is such and such.

If not,

9+1 dimensional world is described by String Theory

The extra 6d space has that particular shape:



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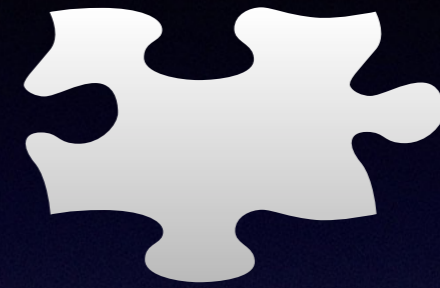


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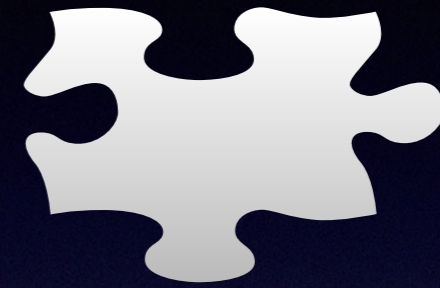


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If this agrees with experiments, claim victory!

9+1 dimensional world is described by String Theory

The extra 6d space has another particular shape:



(specified by yet another equation.)



The 3+1d physics is such and such.

If not, ad infinitum.

- So far, we haven't found *the 6d extra space* which gives this world we live in.
- There's no proof there isn't either.
- It's not that every string theorist is involved this so-far infinite process either.

- At least, string theorists learned a lot about the geometry of the six-dimensional spaces.
- We learned so much about them, and made tons of mathematical conjectures.
- And a lot of mathematicians work on these conjectures now.

- I also made one:

arXiv.org > hep-th > arXiv:0906.3219 Search

High Energy **Physics** – Theory

Liouville Correlation Functions from Four-dimensional Gauge Theories

[Luis F. Alday](#), [Davide Gaiotto](#), [Yuji Tachikawa](#)

(Submitted on 17 Jun 2009 (v1), last revised 9 Feb 2010 (this version, v2))

We conjecture an expression for the Liouville theory conformal blocks and correlation functions on a Riemann surface of genus g and n punctures as the Nekrasov partition function of a certain class of $N=2$ SCFTs recently defined by one of the authors. We conduct extensive tests of the conjecture at genus 0,1.

- which was later proved:

arXiv.org > math > arXiv:1202.2756 Search or

[Mathematics](#) > Quantum Algebra

Cherednik algebras, W algebras and the equivariant cohomology of the moduli space of instantons on A^2

[Olivier Schiffmann](#), [Eric Vasserot](#)

(Submitted on 13 Feb 2012 (v1), last revised 27 Mar 2012 (this version, v2))

We construct a representation of the affine W-algebra of \mathfrak{gl}_r on the equivariant homology space of the moduli space of U_r -instantons on A^2 , and identify the corresponding module. As a corollary we give a proof of a version of the AGT conjecture concerning pure $N=2$ gauge theory for the group $SU(r)$. Another proof has been announced by Maulik and Okounkov. Our approach uses a suitable deformation of the universal enveloping algebra of the Witt algebra $W_{1+\infty}$, which is shown to act on the above homology spaces (for any r) and which specializes to all $W(\mathfrak{gl}_r)$. This deformation is in turn constructed from a limit, as n tends to infinity, of the spherical degenerate double affine Hecke algebra of GL_n .

- which was later proved:

arXiv.org > math > arXiv:1211.1287 Search

Mathematics > Algebraic Geometry

Quantum Groups and Quantum Cohomology

Davesh Maulik, Andrei Okounkov

(Submitted on 6 Nov 2012)

In this paper, we study the classical and quantum equivariant cohomology of Nakajima quiver varieties for a general quiver Q . Using a geometric R -matrix formalism, we construct a Hopf algebra Y_Q , the Yangian of Q , acting on the cohomology of these varieties, and show several results about their basic structure theory. We prove a formula for quantum multiplication by divisors in terms of this Yangian action. The quantum connection can be identified with the trigonometric Casimir connection for Y_Q ; equivalently, the divisor operators correspond to certain elements of Baxter subalgebras of Y_Q . A key role is played by geometric shift operators which can be identified with the quantum KZ difference connection.

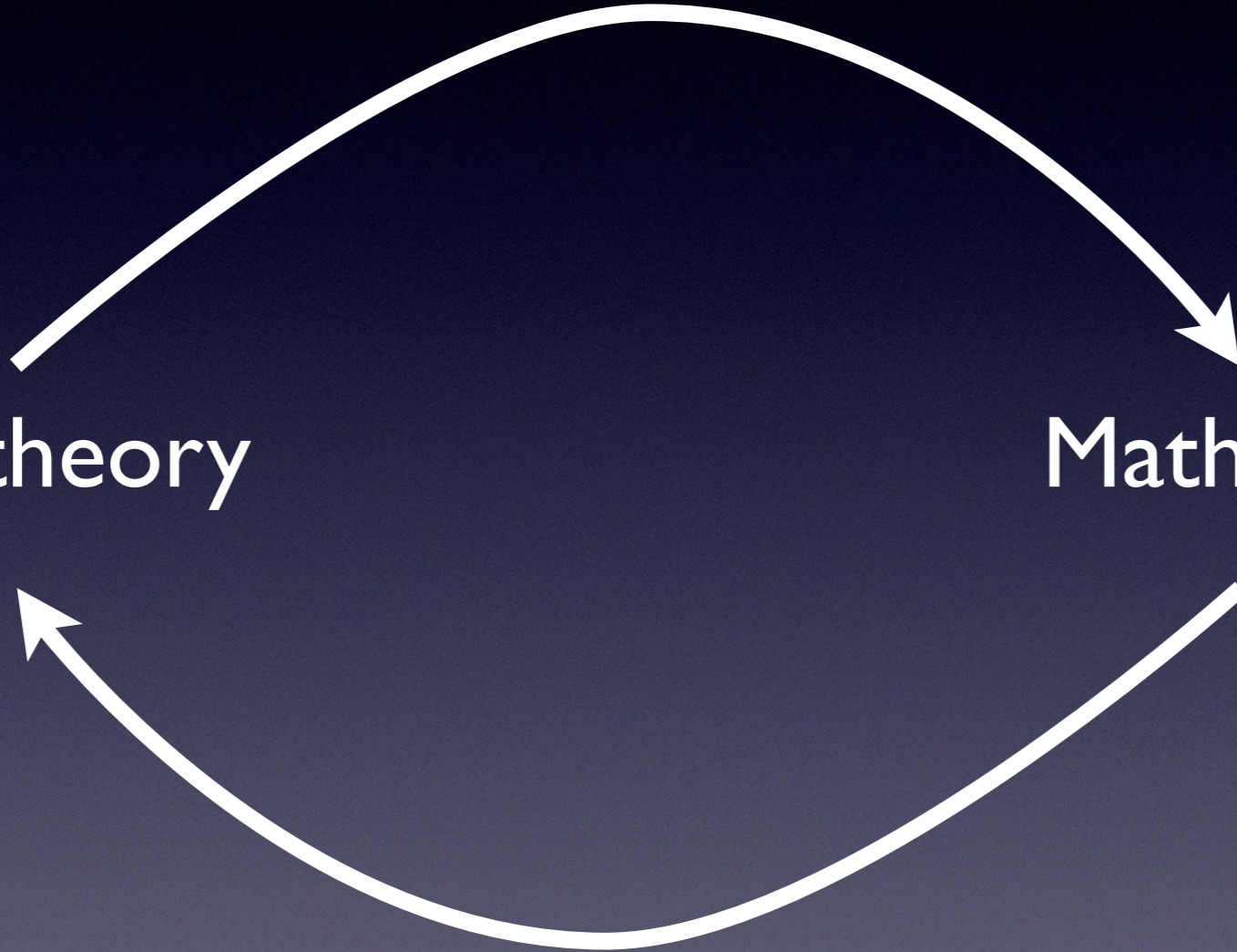
In the second part, we give an extended example of the general theory for moduli spaces of sheaves on C^2 , framed at infinity. Here, the Yangian action is analyzed explicitly in terms of a free field realization; the corresponding R -matrix is closely related to the reflection operator in Liouville field theory. We show that divisor operators generate the quantum ring, which is identified with the full Baxter subalgebras. As a corollary of our construction, we obtain an action of the W -algebra $W(\mathfrak{gl}(r))$ on the equivariant cohomology of rank r moduli spaces, which implies certain conjectures of Alday, Gaiotto, and Tachikawa.

Suggest new conjectures

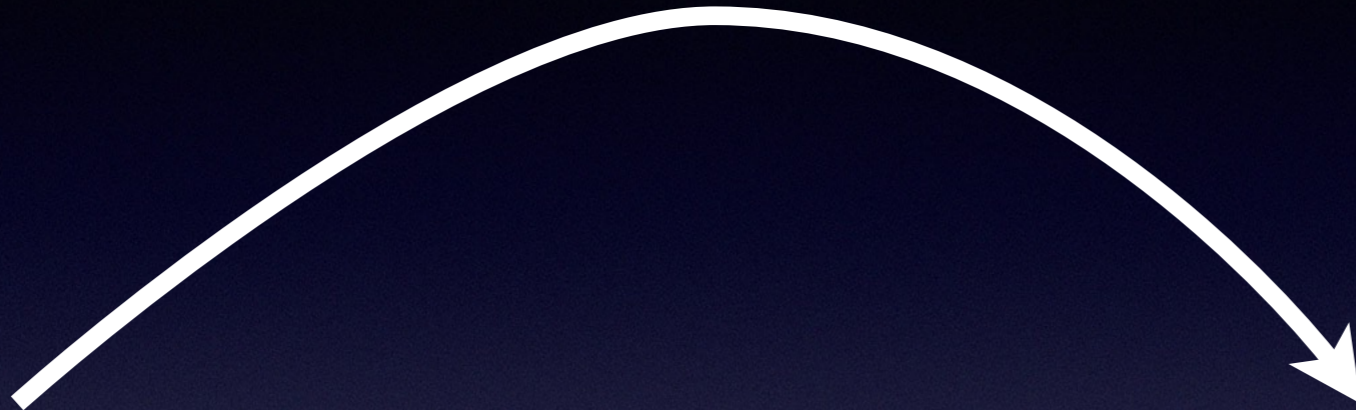
String theory

Mathematics

Present new mathematical results



Suggest new phenomena



Theoretical Science

Experimental Science



Present new experimental results

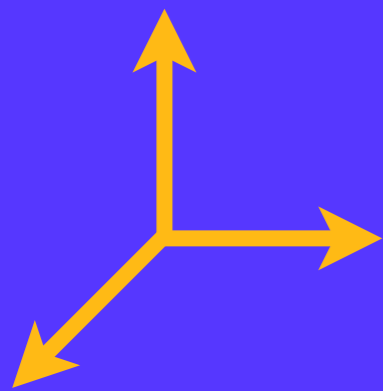
Theoretical Science : Experimental Science

= String theory : Mathematics

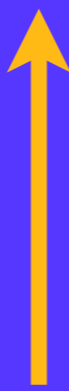
Of course, it can happen that somebody has found
the 6d space



specified by a very nice equation, such that



Space



Time



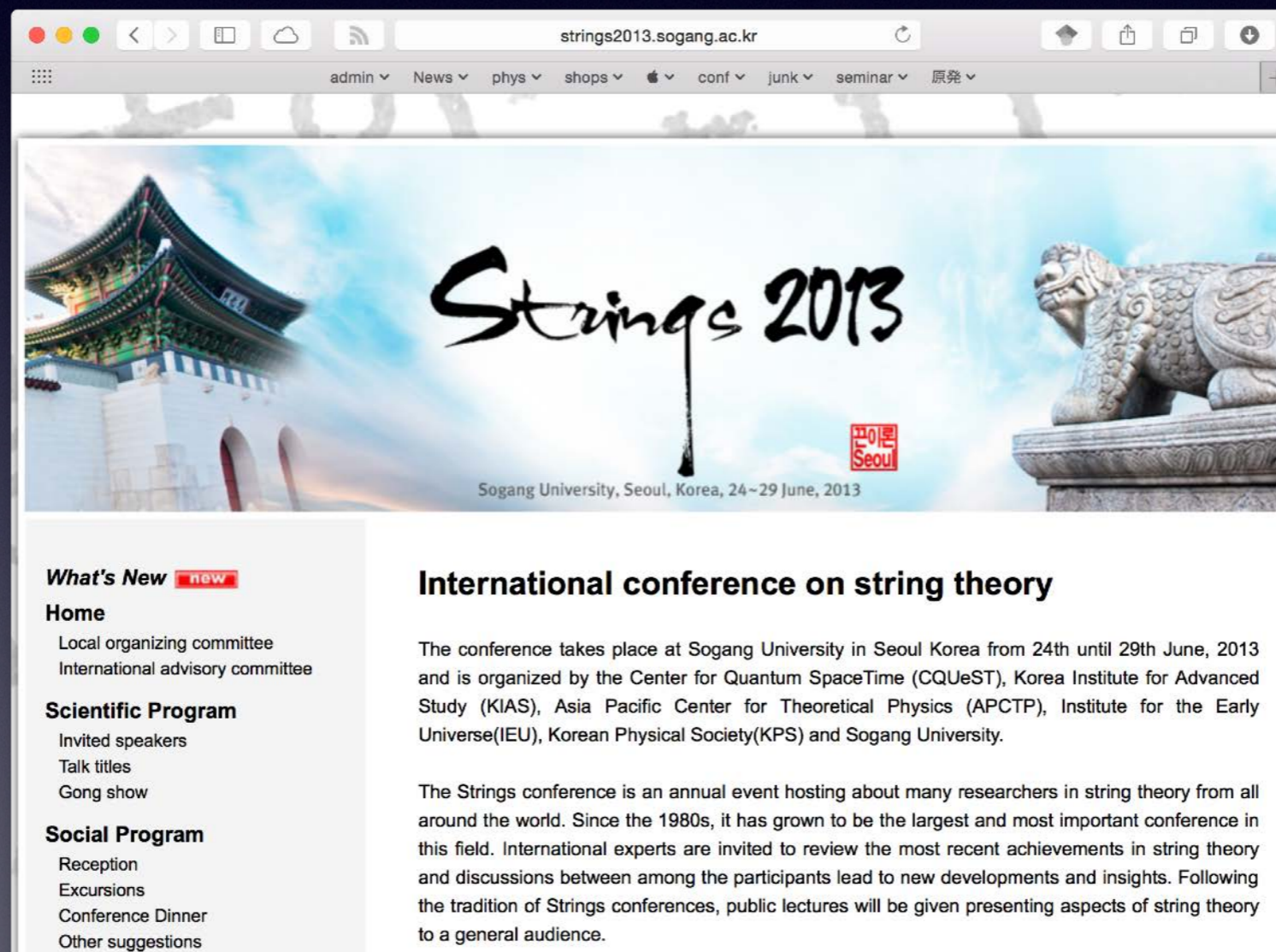
extra 6 dimensions

describes this world, and now is preparing a paper.

- Then string theory becomes a theoretical science.
- Until then, what I do is not really a science.
- That was what I wanted to say today!

- There's an annual international String Theory conference every year

- There's an annual international String Theory conference every year

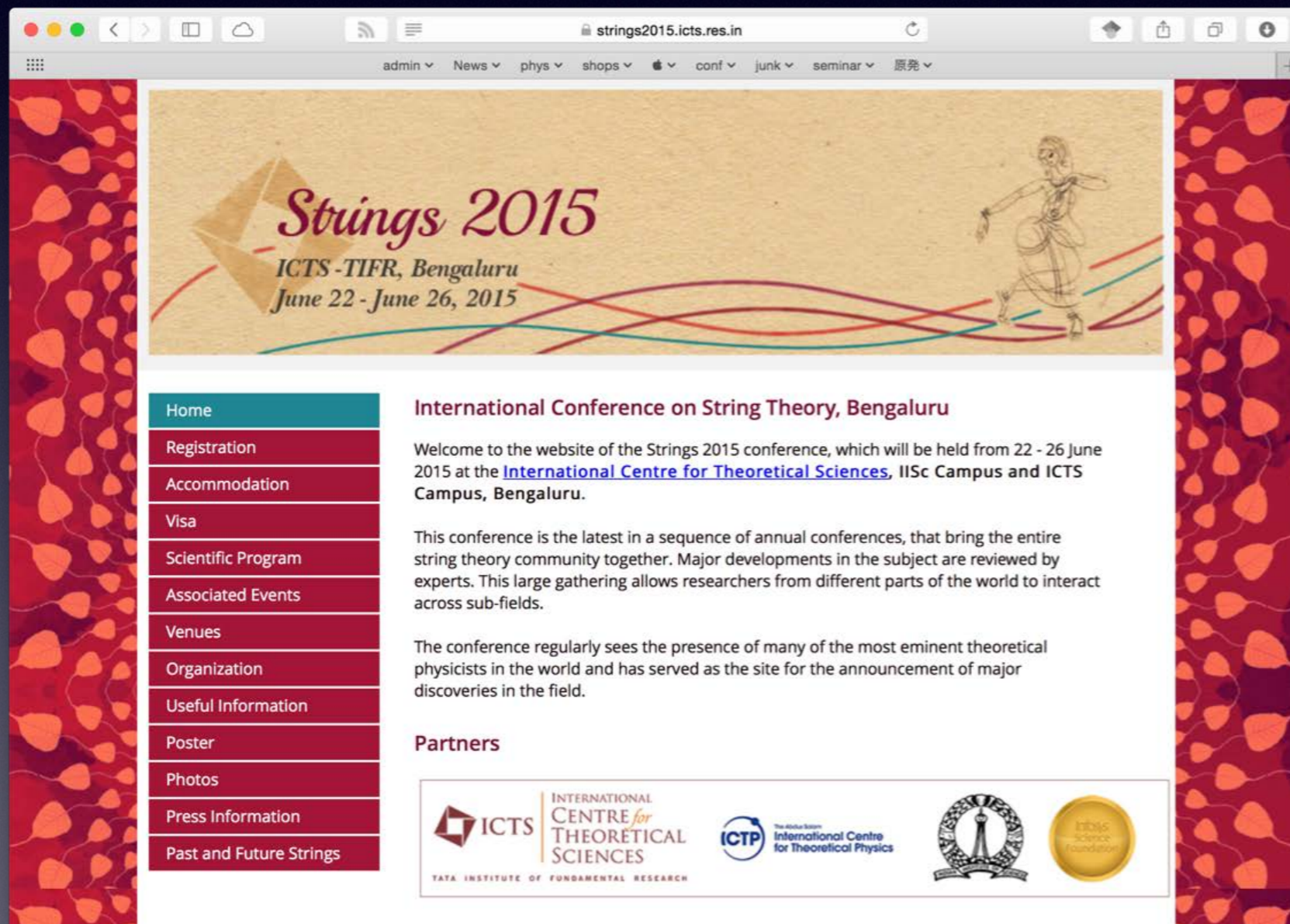


- There's an annual international String Theory conference every year



The screenshot shows a web browser window with the URL `physics.princeton.edu`. The page features a blue header banner with the text "Strings 2014 PRINCETON" and "June 23-27". Logos for Princeton University and the Institute for Advanced Study (IAS) are also present. A left sidebar contains a navigation menu with links such as "Home", "Registration", "Accommodations", "Support", "Participants", "Photos", "Scientific Program", "Invited speakers", "Parallel sessions", "Poster session", "Gong show", "Talk titles", "PITP 2014", "Local", "Directions to Princeton", "Conference location", "Parallel sessions location", "Conference dinner", "Organization", and "International advisory". The main content area is titled "International conference on string theory" and contains the following text: "Strings 2014 will take place at Princeton University and the Institute for Advanced Study from June 23-27. For decades, meetings in the Strings series have been focal points of the field, with experts from around the world presenting new work and reviewing recent developments. Strings 2014 will follow in this tradition, aiming for a unified presentation of the many strands of modern string theory. In addition to plenary talks, this year the program will include parallel sessions, a poster session, a gong show, and vision talks. Please check the Scientific Program for details." Below the text are two photographs: one of a building with a dome (Princeton University) and another of a large building at night (Fuld Hall, Institute for Advanced Study). A footer at the bottom of the page includes the text "Princeton University." and "Fuld Hall, Institute for Advanced Study." and "to a general audience."

- There's an annual international String Theory conference every year



The screenshot shows a web browser window with the URL `strings2015.icts.res.in`. The page features a navigation menu with items like 'admin', 'News', 'phys', 'shops', 'conf', 'junk', 'seminar', and '原免'. The main content area has a header with the text 'Strings 2015' and 'ICTS - TIFR, Bengaluru June 22 - June 26, 2015'. Below this is a sidebar with a list of links: Home, Registration, Accommodation, Visa, Scientific Program, Associated Events, Venues, Organization, Useful Information, Poster, Photos, Press Information, and Past and Future Strings. The main text area contains a welcome message, a description of the conference, and a 'Partners' section with logos for ICTS, ICTP, and the IISc Science Foundation.

strings2015.icts.res.in

admin News phys shops conf junk seminar 原免

Strings 2015

ICTS - TIFR, Bengaluru
June 22 - June 26, 2015

Home
Registration
Accommodation
Visa
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Useful Information
Poster
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Press Information
Past and Future Strings

International Conference on String Theory, Bengaluru

Welcome to the website of the Strings 2015 conference, which will be held from 22 - 26 June 2015 at the [International Centre for Theoretical Sciences, IISc Campus and ICTS Campus, Bengaluru](#).

This conference is the latest in a sequence of annual conferences, that bring the entire string theory community together. Major developments in the subject are reviewed by experts. This large gathering allows researchers from different parts of the world to interact across sub-fields.

The conference regularly sees the presence of many of the most eminent theoretical physicists in the world and has served as the site for the announcement of major discoveries in the field.

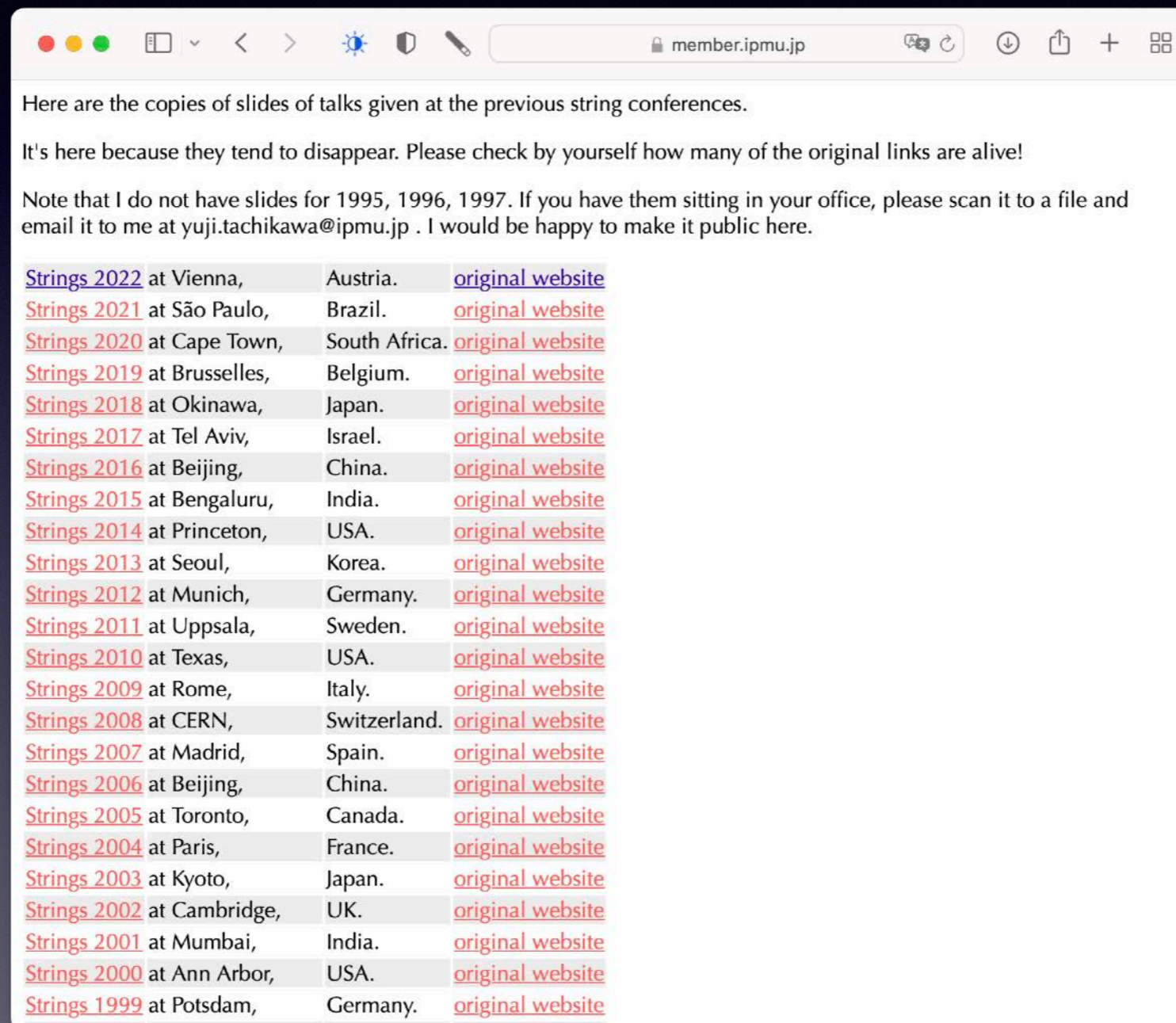
Partners

ICTS INTERNATIONAL CENTRE for THEORETICAL SCIENCES
TATA INSTITUTE OF FUNDAMENTAL RESEARCH

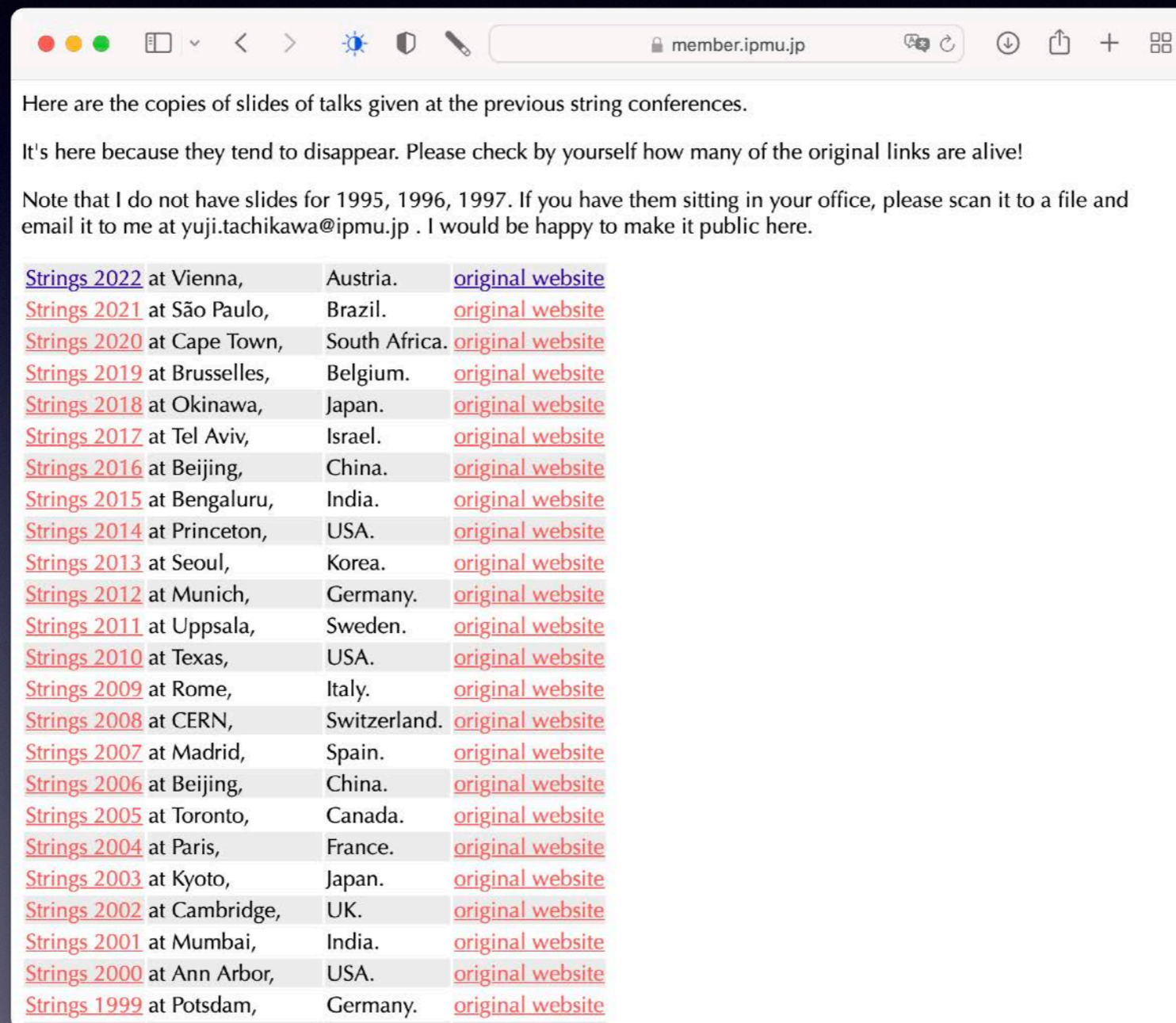
ICTP The Abdus Salam International Centre for Theoretical Physics

IISc Science Foundation

- I maintain a website collecting slides from the annual String Theory conferences.



- It contains roughly 30 talks x 25 years, and gives a great overview.



Here are the copies of slides of talks given at the previous string conferences.

It's here because they tend to disappear. Please check by yourself how many of the original links are alive!

Note that I do not have slides for 1995, 1996, 1997. If you have them sitting in your office, please scan it to a file and email it to me at yuji.tachikawa@ipmu.jp . I would be happy to make it public here.

Strings 2022	at Vienna,	Austria.	original website
Strings 2021	at São Paulo,	Brazil.	original website
Strings 2020	at Cape Town,	South Africa.	original website
Strings 2019	at Bruxelles,	Belgium.	original website
Strings 2018	at Okinawa,	Japan.	original website
Strings 2017	at Tel Aviv,	Israel.	original website
Strings 2016	at Beijing,	China.	original website
Strings 2015	at Bengaluru,	India.	original website
Strings 2014	at Princeton,	USA.	original website
Strings 2013	at Seoul,	Korea.	original website
Strings 2012	at Munich,	Germany.	original website
Strings 2011	at Uppsala,	Sweden.	original website
Strings 2010	at Texas,	USA.	original website
Strings 2009	at Rome,	Italy.	original website
Strings 2008	at CERN,	Switzerland.	original website
Strings 2007	at Madrid,	Spain.	original website
Strings 2006	at Beijing,	China.	original website
Strings 2005	at Toronto,	Canada.	original website
Strings 2004	at Paris,	France.	original website
Strings 2003	at Kyoto,	Japan.	original website
Strings 2002	at Cambridge,	UK.	original website
Strings 2001	at Mumbai,	India.	original website
Strings 2000	at Ann Arbor,	USA.	original website
Strings 1999	at Potsdam,	Germany.	original website

- If you are interested in string theory, you might want to have a look.

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- I also wrote an iPad app to read slides at the String Theory conferences. It's free.

The screenshot shows the iTunes Preview page for the 'Strings Conferences' app. The page is displayed in a browser window with the URL 'itunes.apple.com'. The navigation bar at the top includes links for 'admin', 'News', 'phys', 'shops', 'Apple', 'conf', 'junk', 'seminar', and '原発'. The main navigation bar includes 'ストア', 'Mac', 'iPhone', 'Watch', 'iPad', 'iPod', 'iTunes', and 'サポート'. The app title 'Strings Conferences' is prominently displayed, along with the developer's name 'By Yuji Tachikawa'. A colorful, abstract image of a string theory manifold is shown next to the app icon. The description states: 'Almost fifteen years of (non-)progress of String Theory on your iPad! With this app, you can easily navigate all the slides from the past Strings conferences, from 1998 to 2014.' The 'What's New in Version 1.5' section mentions an update including Strings 2014 and the look & feel of iOS 7. The 'iPad Screenshots' section shows two screenshots: one of a slide titled 'Ingredients and Y Tachikawa (IAS Princeton), 3 of 36' with bullet points about $SU(N)$ and $2N$ fundamentals, and another of a slide titled 'Strings 2003' listing speakers like Mina Aganagic, Constantin Bachas, Tom Banks, Nathan Berkovits, Raphael Bousso, Mirjam Cvetič, and Atish Dabholkar. The app is listed as free, in the Education category, and has a rating of 4+.

itunes.apple.com

admin News phys shops Apple conf junk seminar 原発

ストア Mac iPhone Watch iPad iPod iTunes サポート


iTunes Preview

概要 ミュージック ビデオ iTunesのランキング

Strings Conferences

By Yuji Tachikawa

Open iTunes to buy and download apps.



[View in iTunes](#)

Free
Category: [Education](#)
Updated: Jul 07, 2014
Version: 1.5
Size: 0.2 MB
Language: English
Seller: Yuji Tachikawa
© Yuji Tachikawa, 2013
[Rated 4+](#)

Compatibility: Requires iOS 7.0 or later. Compatible with iPad.

Description

Almost fifteen years of (non-)progress of String Theory on your iPad! With this app, you can easily navigate all the slides from the past Strings conferences, from 1998 to 2014.

[Strings Conferences Support](#)

What's New in Version 1.5

Update including Strings 2014. Look & feel of iOS 7.

iPad Screenshots

