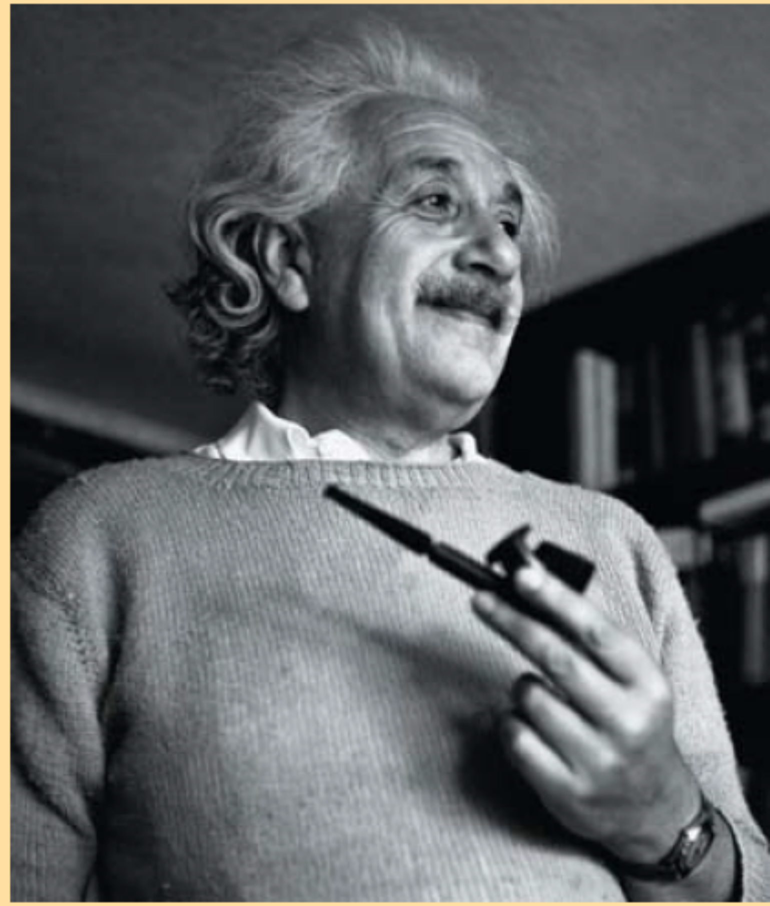
Search of Quantum Gravity with Neutrinos: Hawking's Unfulfilled Dream

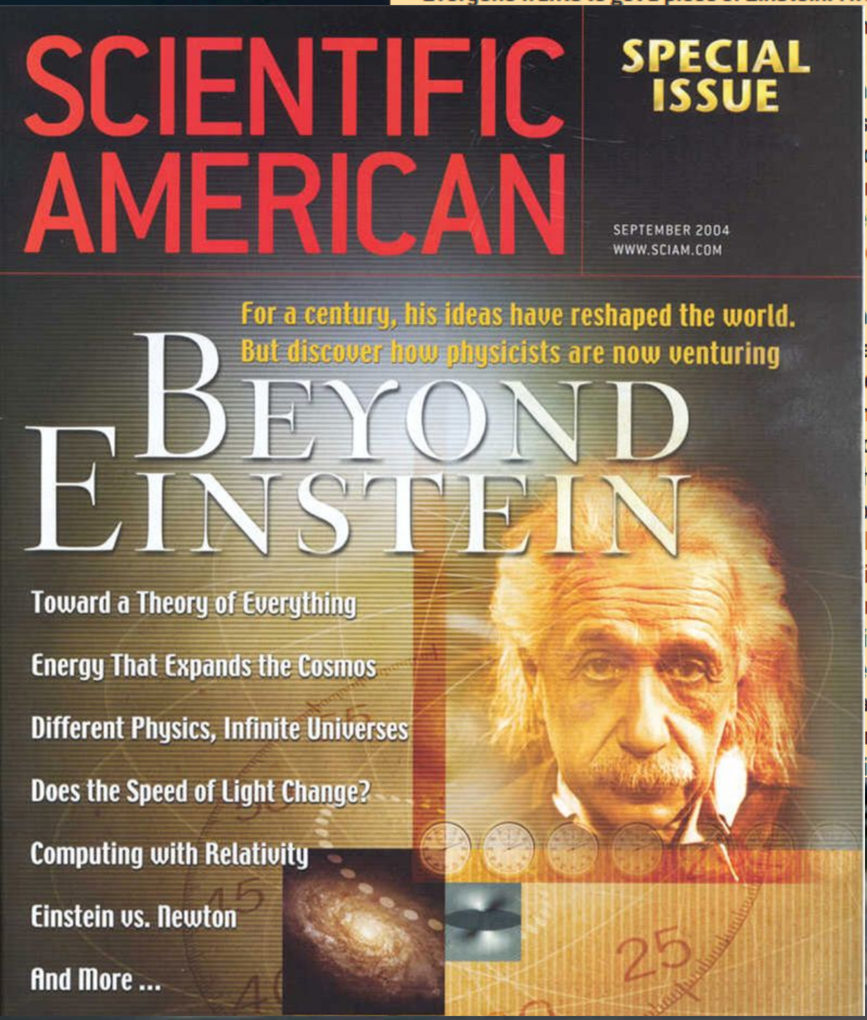
ICONOCLASTS

Toppling the Giant

Everyone wants to get a piece of Einstein. Two of the three most
...itists and science
...unified theory
...s to have proved his
...s: perpetual-motion
...cannibals seeking the
...misguided amateurs seem
...in they will acquire all his
...disprove is their own

...ists. Many serious and
...eyond Einstein, in the way
...e accompanying article
...ntal search for departures
...discusses is based on a
...h all plausible relativity-
...of particle physics. This
...ble deviation that could
...igh-energy pinnacle of the
...ry.
...ity have attracted specific
...name "doubly special
...nni Amelino-Camelia of
...r by Lee Smolin of the
...in Ontario, João Magueijo





Teppei Katori (@teppeikatori)
Queen Mary University of London
Pint of Science, The Horseshoe, London
May 21, 2019

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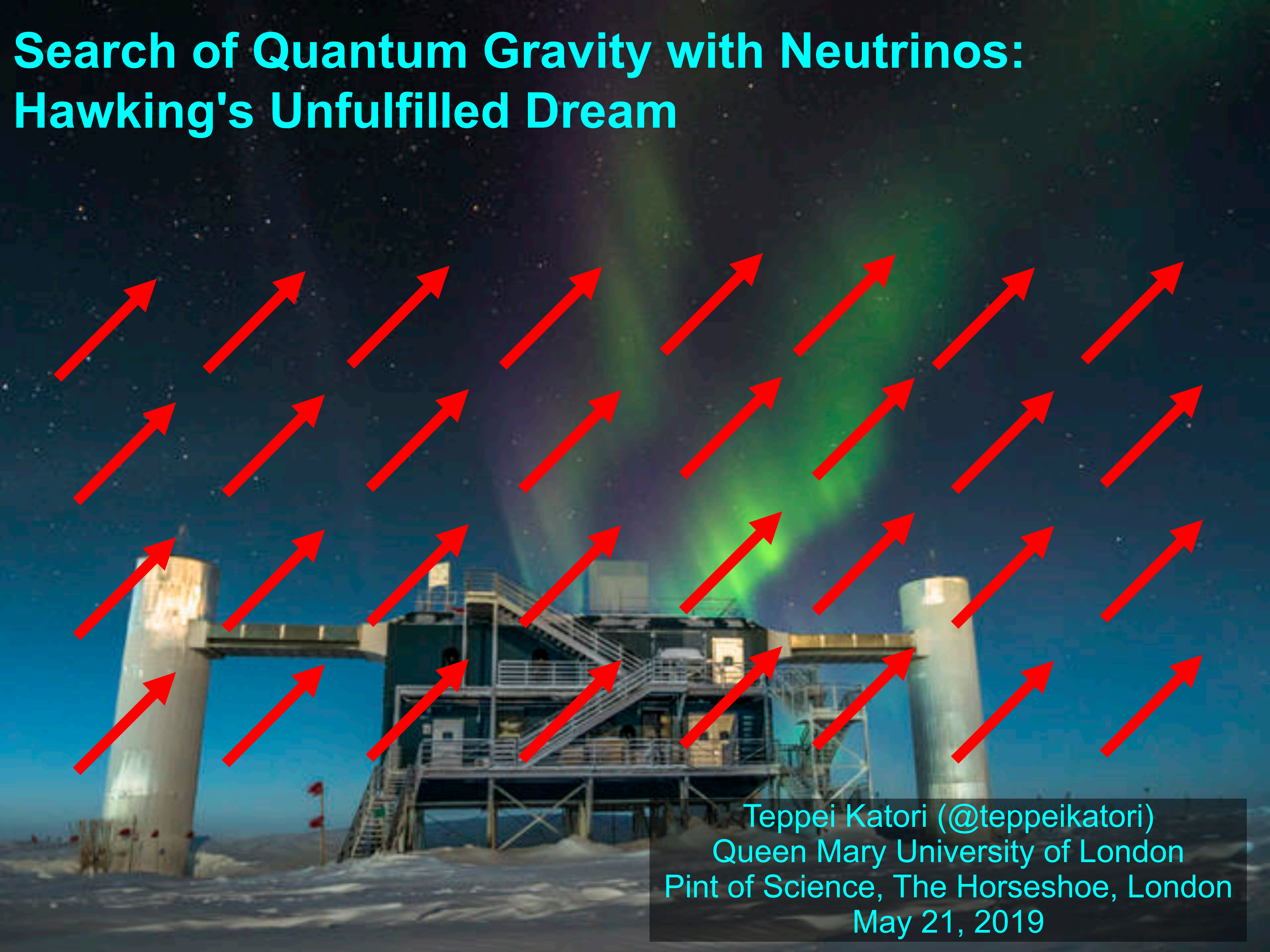

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Emmy Noether (1882-1935)

Mathematician from Germany

Noether's Theorem
"Every conservation law is a consequence of corresponding symmetry"

- conservation of energy
- conservation of electric charge
- prediction of Higgs boson

etc

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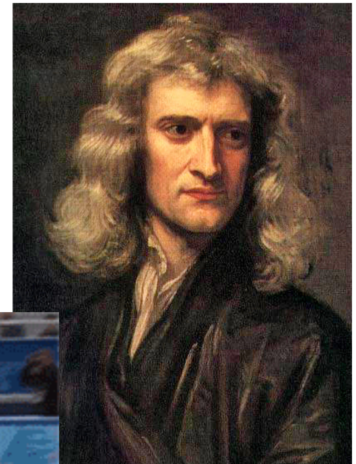
Conservation of Angular Momentum

Isaac Newton



Rotating objects keep rotating

Conservation of
angular momentum

Yulia Lipnitskaya (Russia)

Conservation of Angular Momentum

Rotating objects keep rotating

Conservation of
angular momentum

Emmy Noether

Universe has
no special direction
→ Universe has
rotational symmetry
(Lorentz symmetry)

Yulia Lipnitskaya (Russia)

→

Isotropy of the Space
(no directionality)

Lorentz Symmetry and Special Relativity

Einstein's theory of special relativity is based on the Lorentz symmetry

Lorentz symmetry is the isotropy of the space-time

Einstein and Lorentz

If the universe has a special direction
Space doesn't have Lorentz symmetry
→ Lorentz transformation is violated, or Lorentz violation

Angular momentum is not conserved,
so Yulia Lipnitskaya cannot spin so much!

Since Yulia Lipnitskaya CAN spin so much,
Lorentz violation is very weak effect, even if existed

→ you need very precise measurements to find it

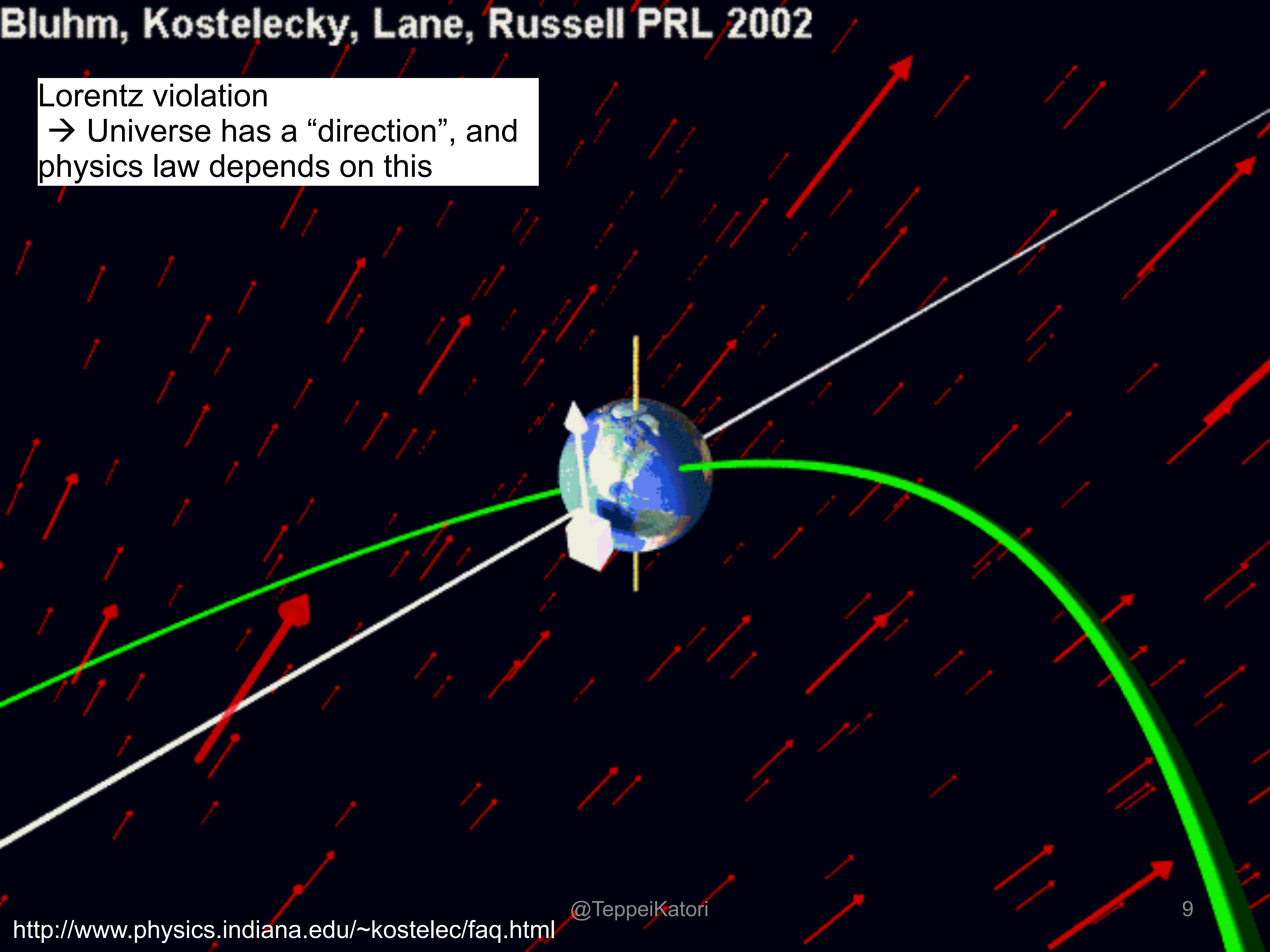
Lorentz Symmetry and Theory of Everything

Quantum Gravity or “Theory of Everything” (such as superstring theory, quantum loop gravity, etc) allow tiny amount of Lorentz violation

→ Discovery of Lorentz violation could be the first evidence of Theory of Everything!

Einstein and Lorentz

Stephen Hawking imposter and someone

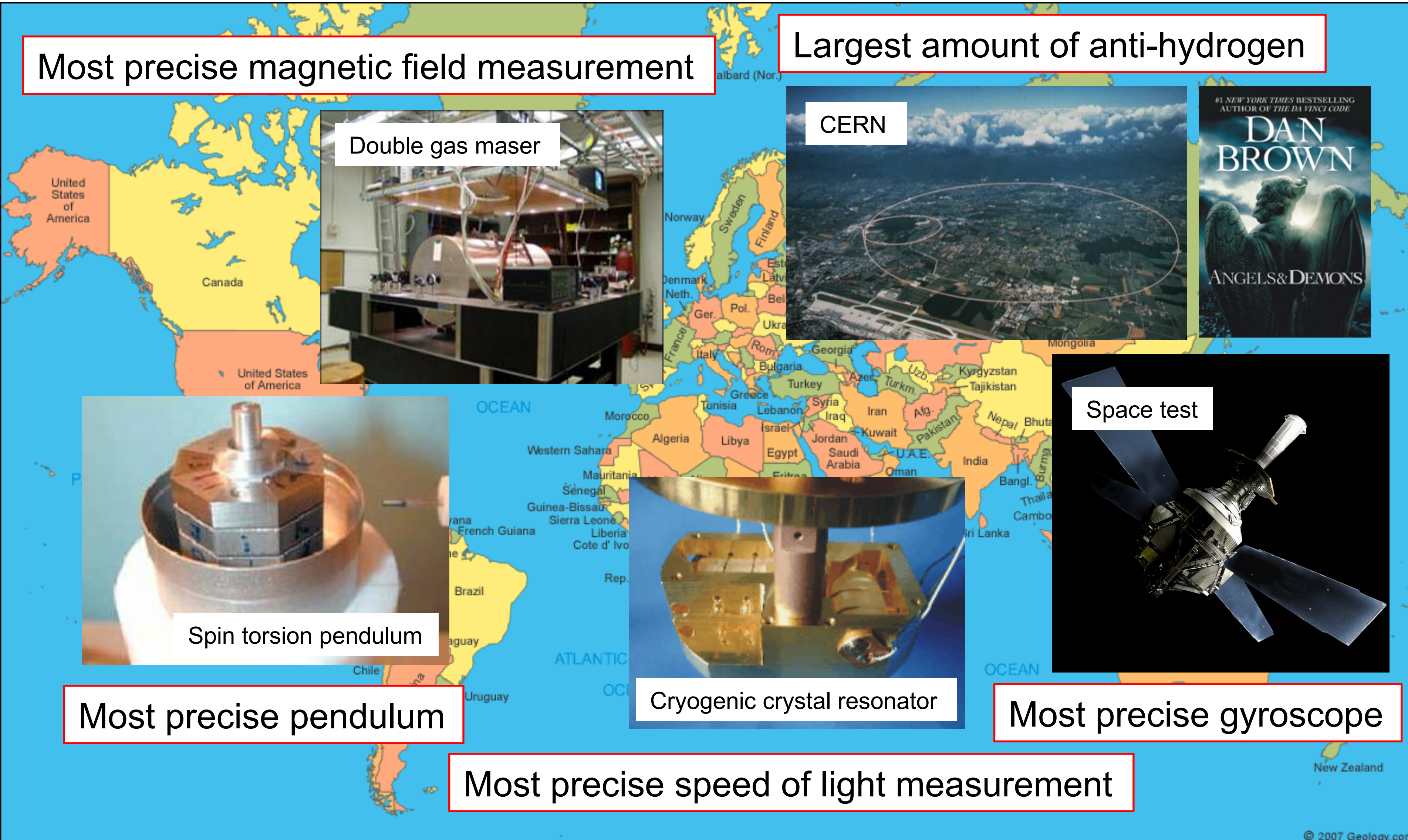


Lorentz violation
→ Universe has a "direction", and physics law depends on this

http://www.physics.indiana.edu/~kostelec/faq.html

The race to defeat Einstein

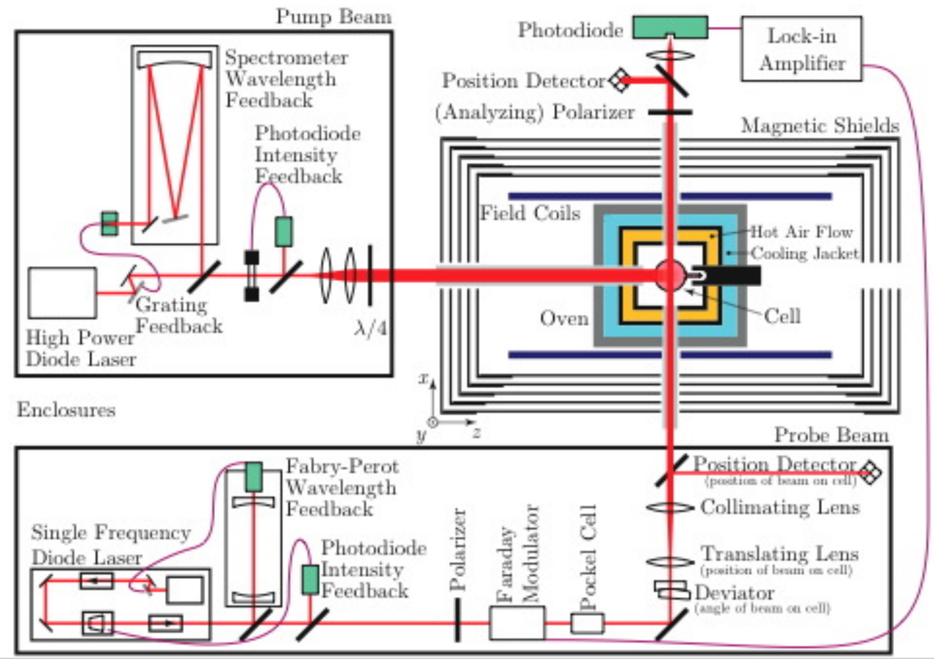
Most precise something



Double Noble Gas Maser

A type of atomic clock very sensitive to a tiny magnetic field

→ Lorentz violation is not discovered



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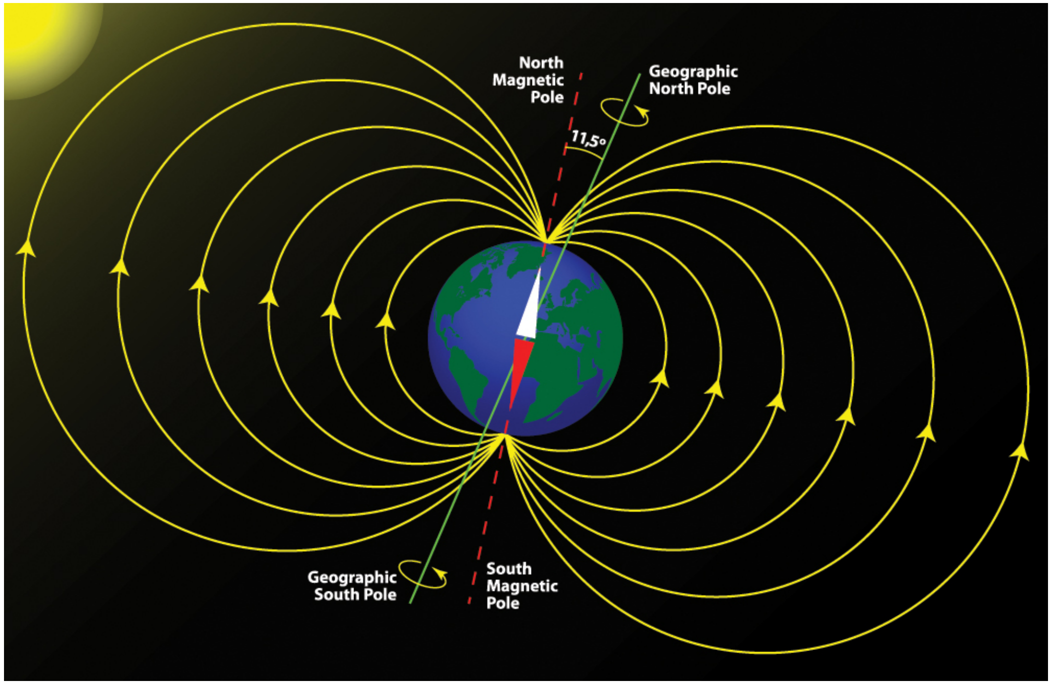
Double Noble Gas Maser

A type of atomic clock very sensitive to a tiny magnetic field

→ Lorentz violation is not discovered

The Earth magnetic field gives error. To improve sensitivity, scientists want to repeat the measurement at special location on the Earth (special earth magnetic field configuration)

Princeton university group vs. Amherst college group



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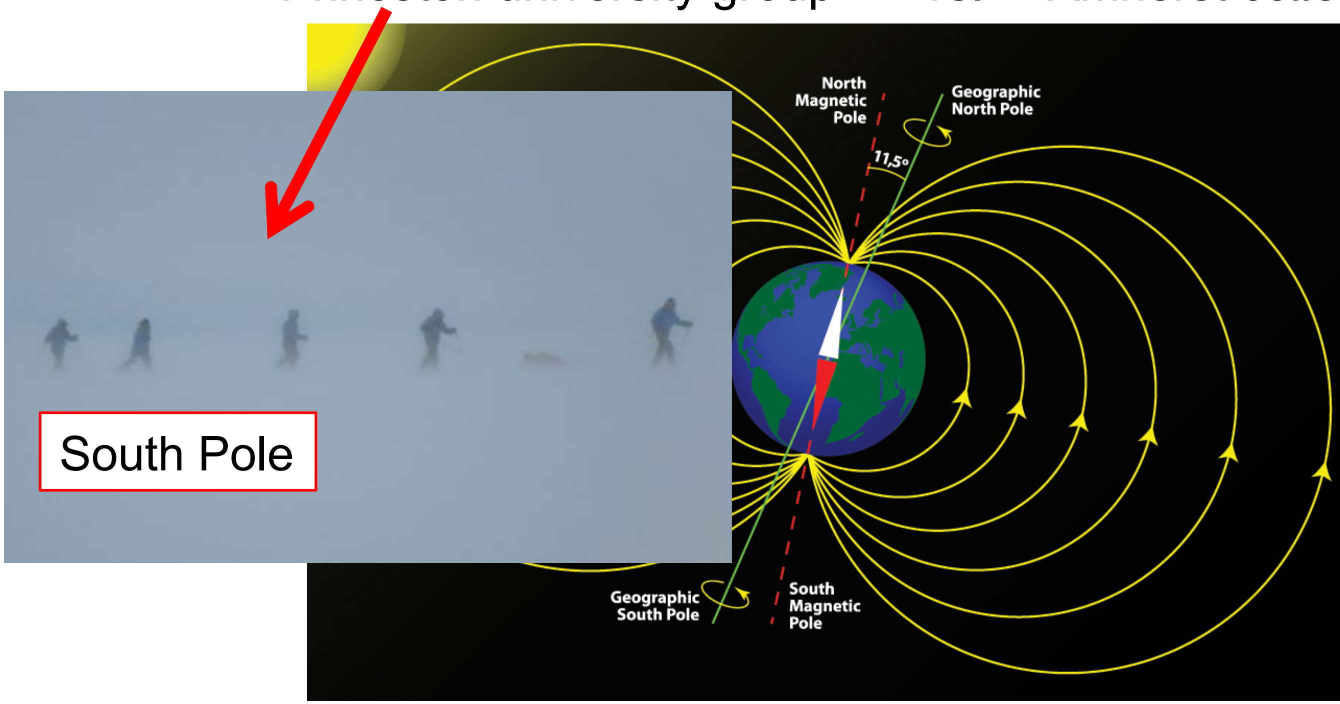

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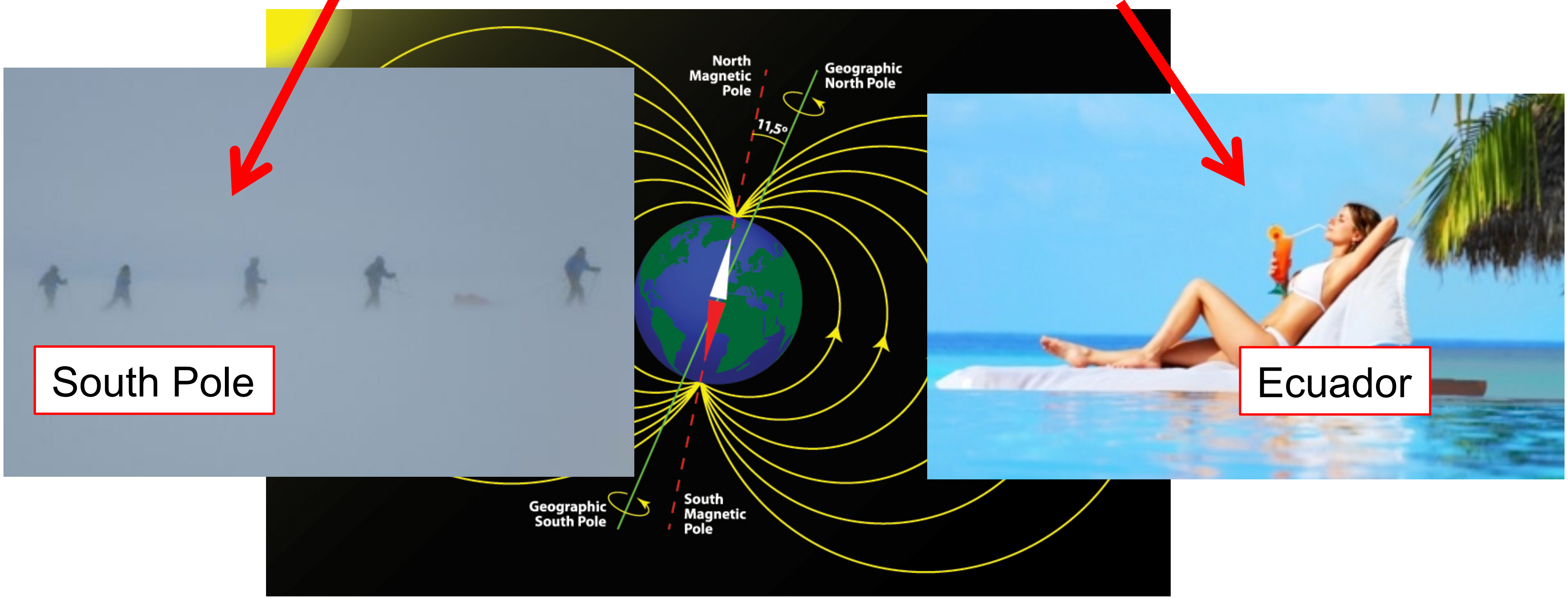

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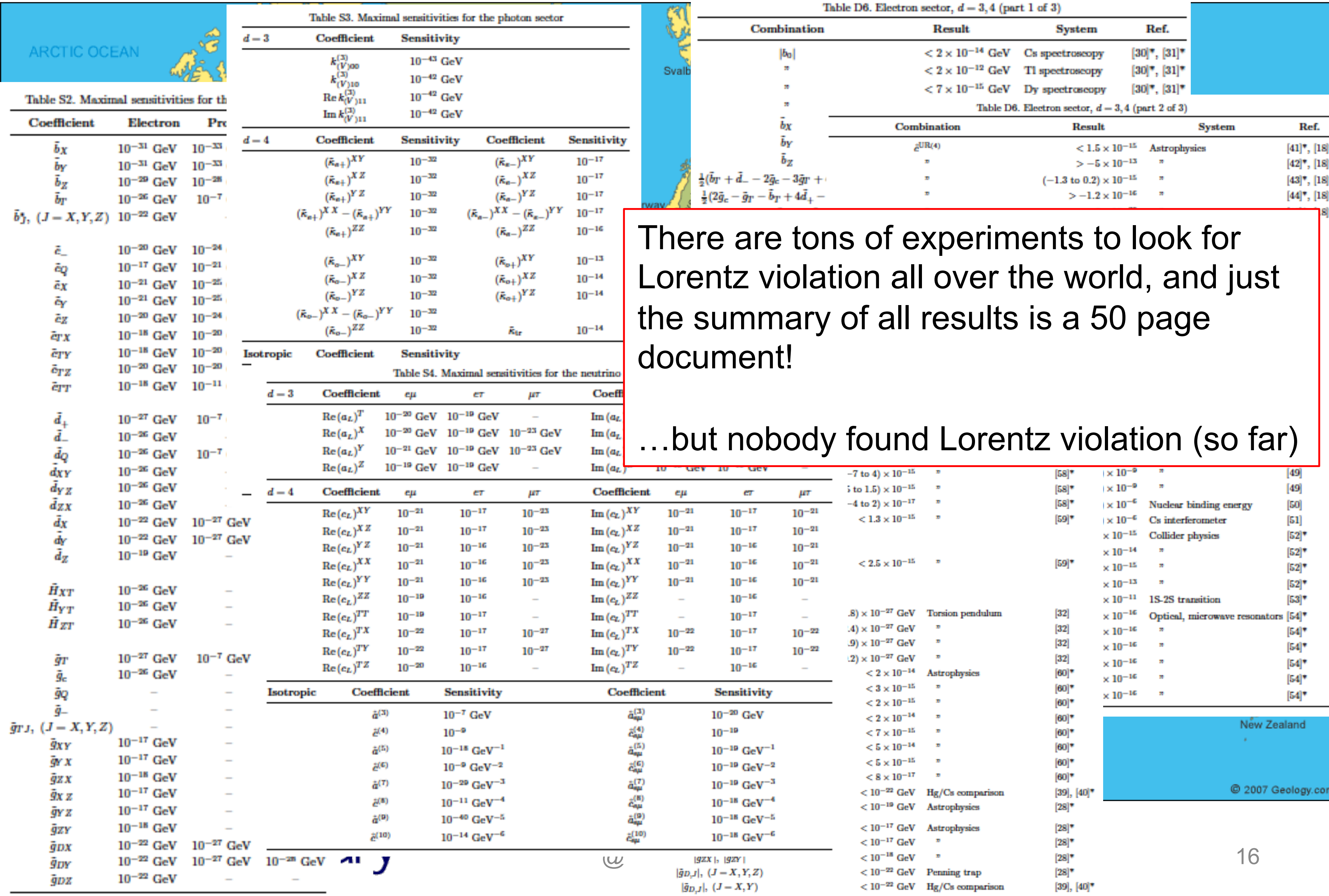
The race to defeat Einstein

Most precise something

The race to defeat Einstein

Most precise something

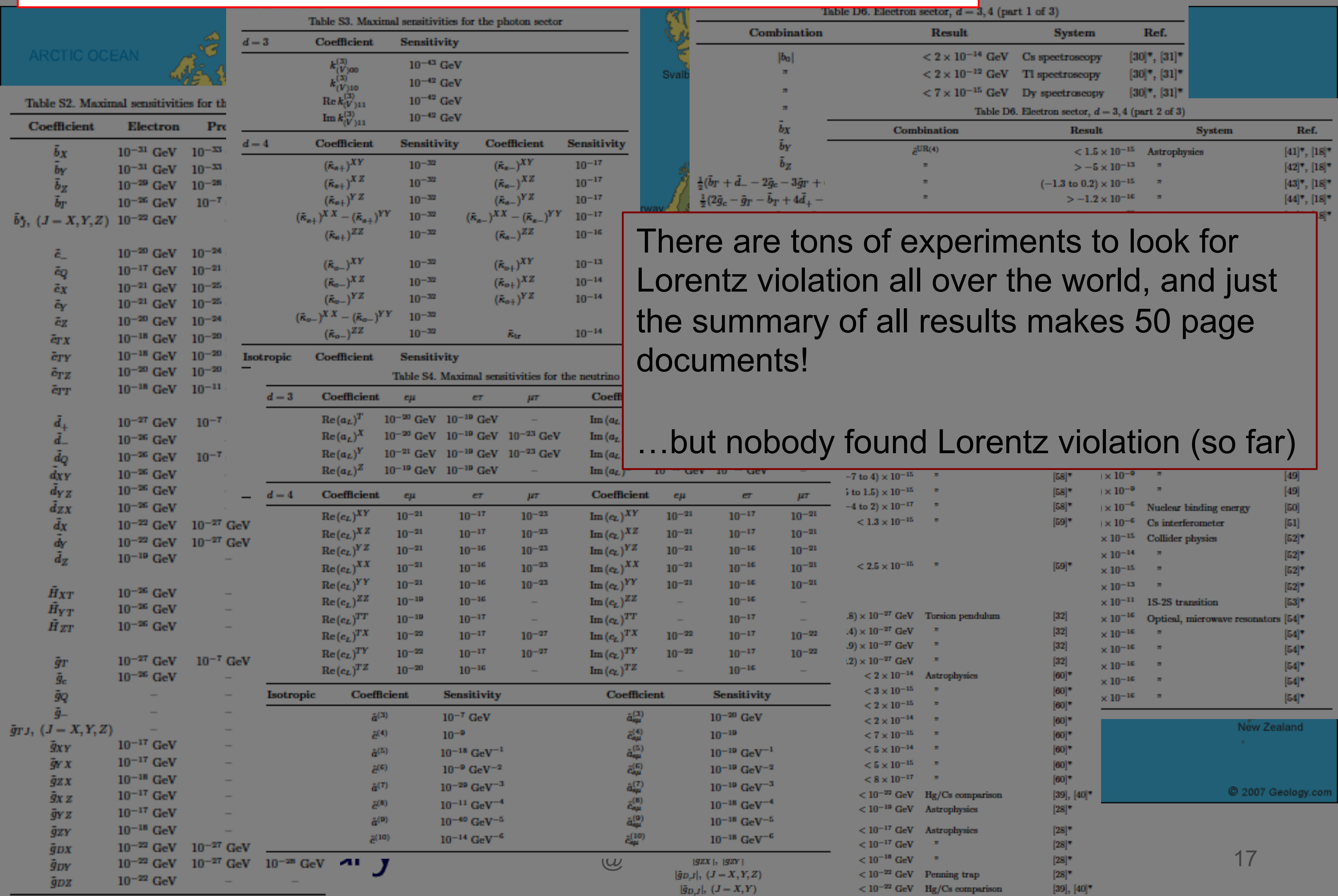


There are tons of experiments to look for Lorentz violation all over the world, and just the summary of all results is a 50 page document!

…but nobody found Lorentz violation (so far)

So far no experiments find Lorentz violation…

Most precise something



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Most precise something

“Extraordinary discovery requires extraordinary evidence”
- Carl Sagan

There are to
Lorentz viola
the summary
documents!

…but nobod

st
far)

So far no experiments find Lorentz violation…

"Extraordinary discovery requires extraordinary evidence"
- Carl Sagan

↓

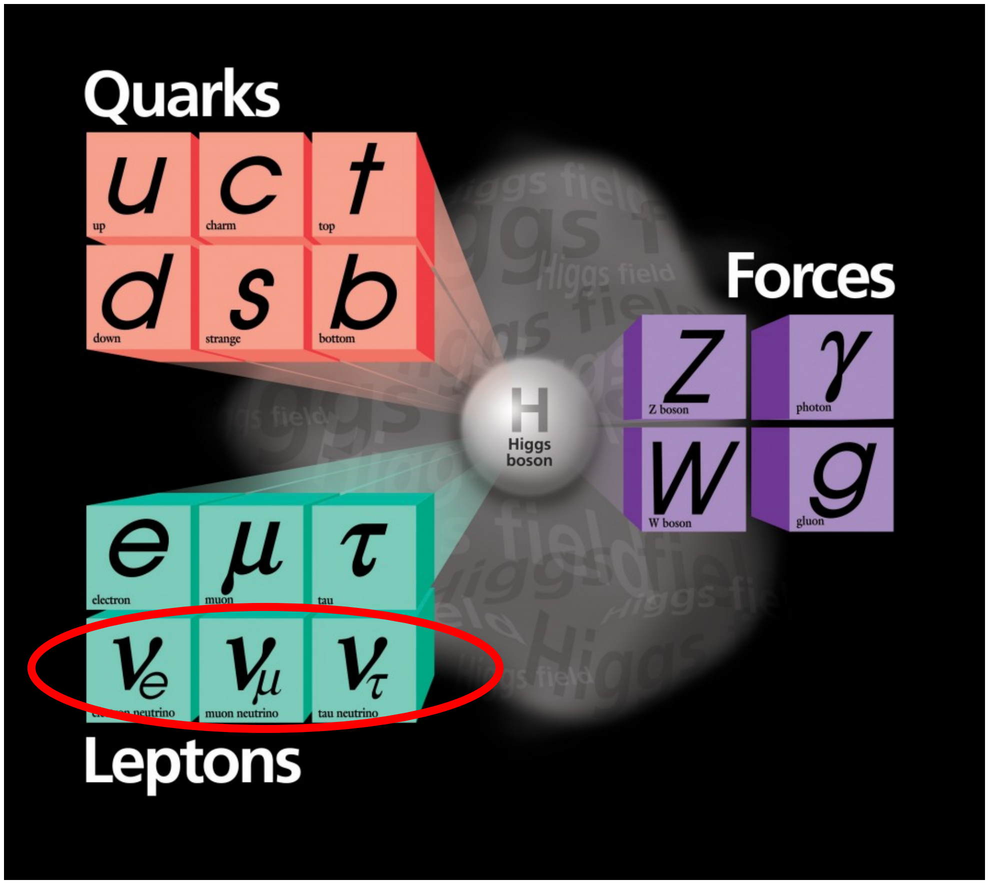
"Extraordinary discovery requires extraordinary particles"
- Teppei

↓

Neutrino!

Search of Lorentz Violation with Neutrinos

People use ordinary particles to look for Lorentz violation, but cannot find
→ Maybe we should use extraordinary particles, such as neutrinos

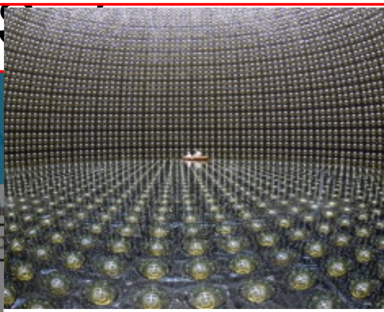


Neutrinos
- 3 types
- neutral (no electric charge)
- extremely tiny mass
- second most abundant particles in the universe (after photons)

- neutrinos interact very very weakly with matter, so extremely difficult to detect

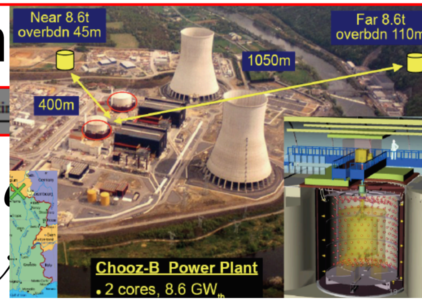
ex) Neutrinos from the Sun
~1 trillion neutrinos pass through your body every second, and you have 25% chance to hit one neutrino in 80 years

Super-Kamiokande (Japan)



PRD91(2015)052003

Double Chooz (France)



PRD86(2013)112009

MINOS ND (USA)

PRL101(2008)151601

MiniBooNE (USA)

PLB718(2013)1303

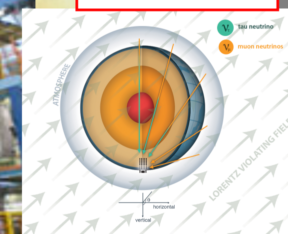
Daya Bay (China)

PRD98(2018)092013

MINOS FD (USA)

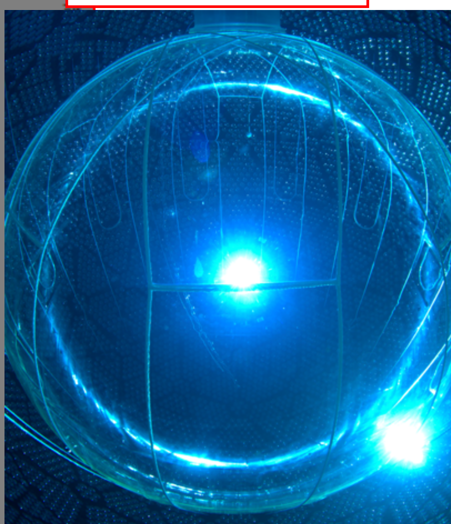
PRL105(2010)151601

IceCube-86



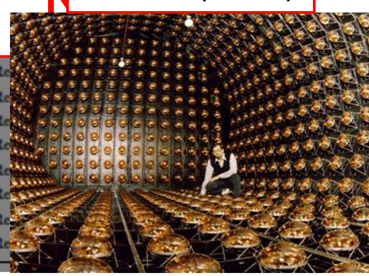
Nature Physics 14(2018)961

SNO (Canada)



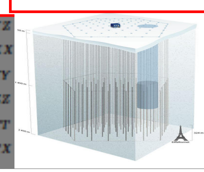
PRD98(2018)112013

LSND (USA)



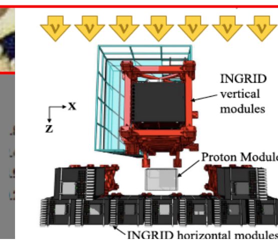
PRD72(2005)076004

IceCube-40



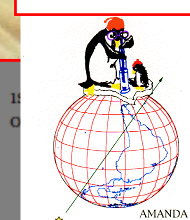
PRD82(2010)112003

T2K ND (Japan)



PRD95(2017)111101

AMANDA



PRD79(2009)102005

There are searches for Lorentz violations with neutrinos across the globe, however, neutrinos appear to behave normal in space-time…, maybe these neutrinos are not extraordinary enough?

Searc

ARCTIC OCEA

Table S2. Maximal

→ IceCube measures the ultra-high-energy extragalactic neutrinos

IceCube Neutrino Observatory (Antarctica)

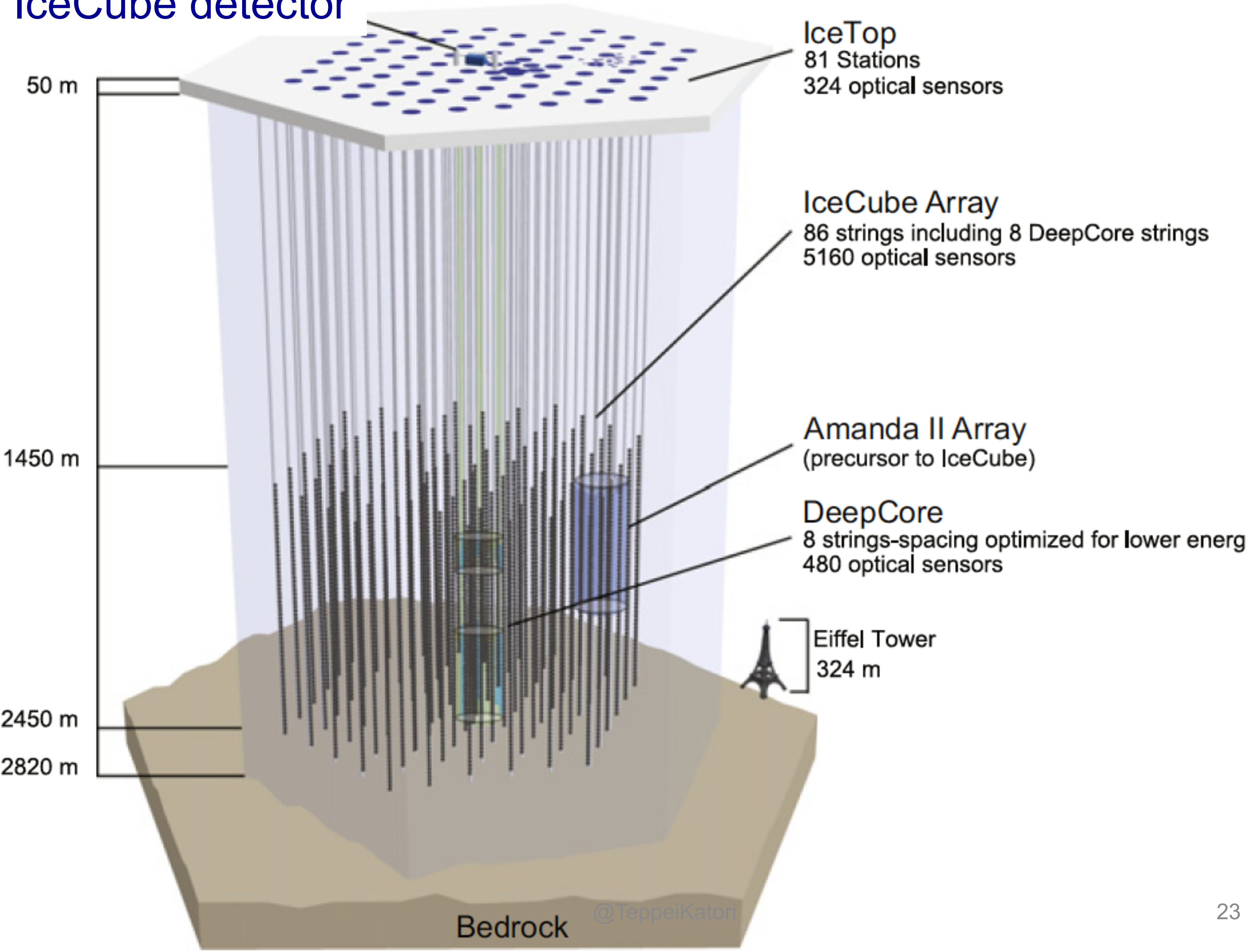
ook for
, and just
50 page

on (so far)

"Extraordinary discovery requires extraordinary particles with the extraordinary energy and extraordinary propagation distance"

- Teppei

IceCube detector



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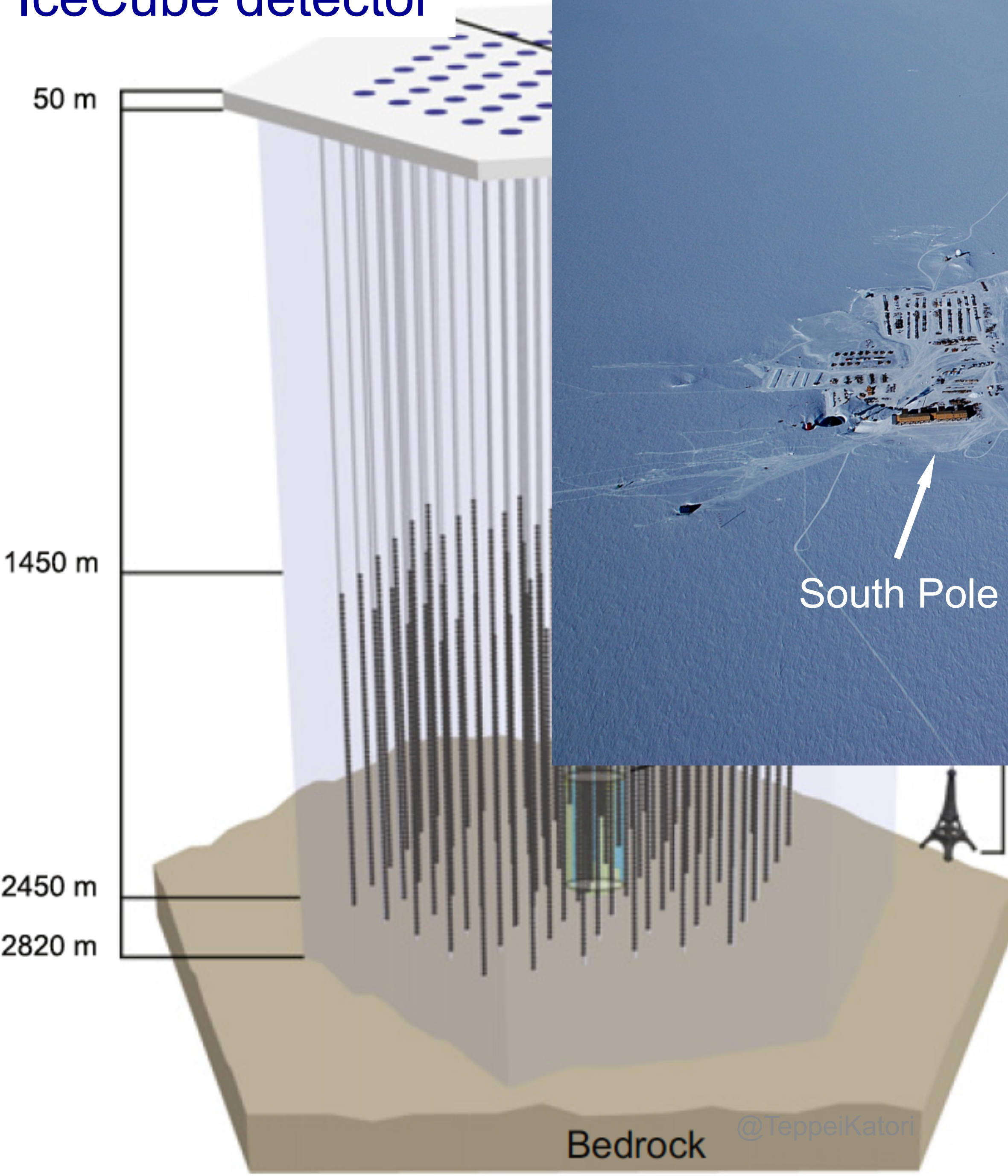

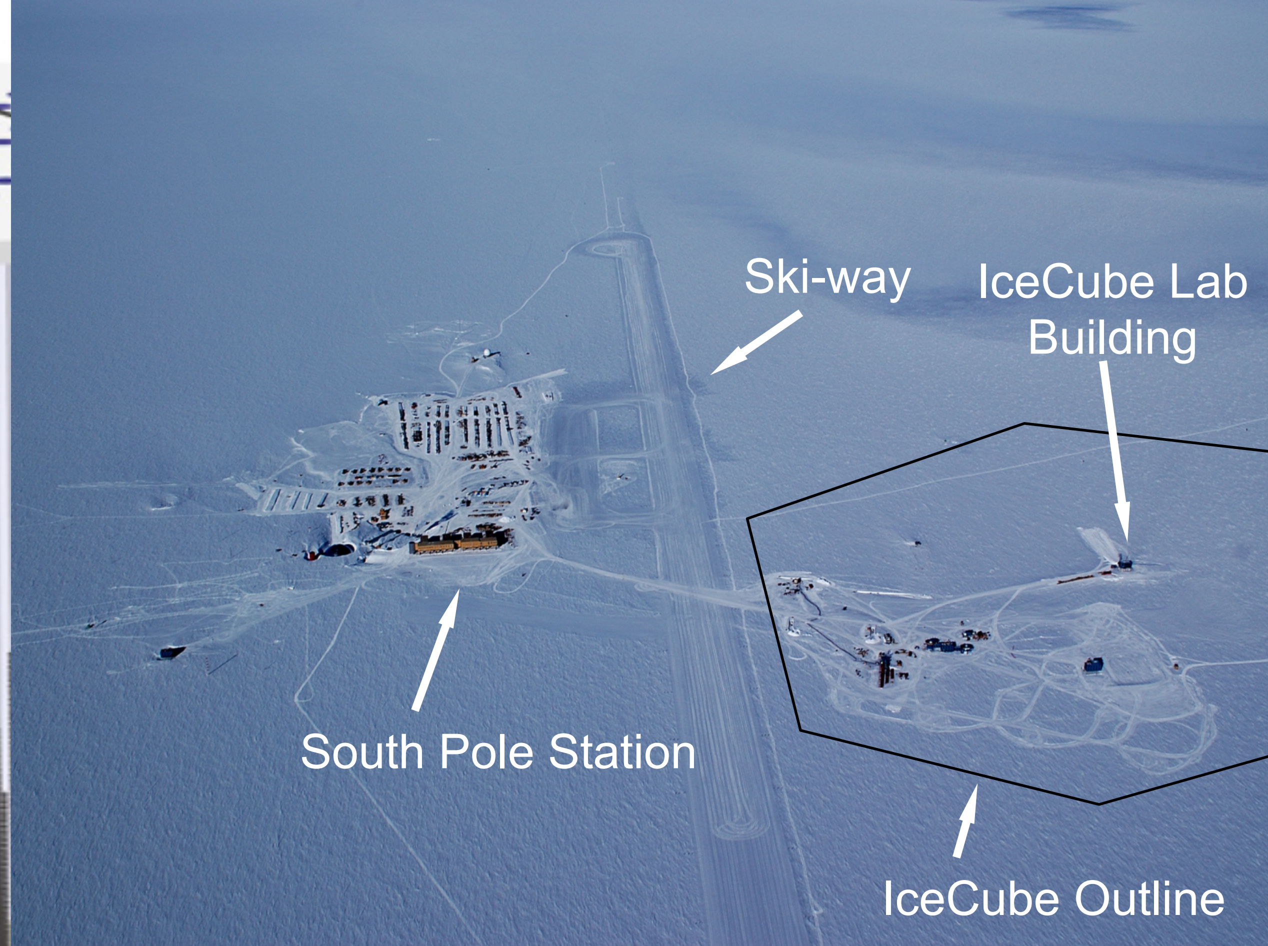

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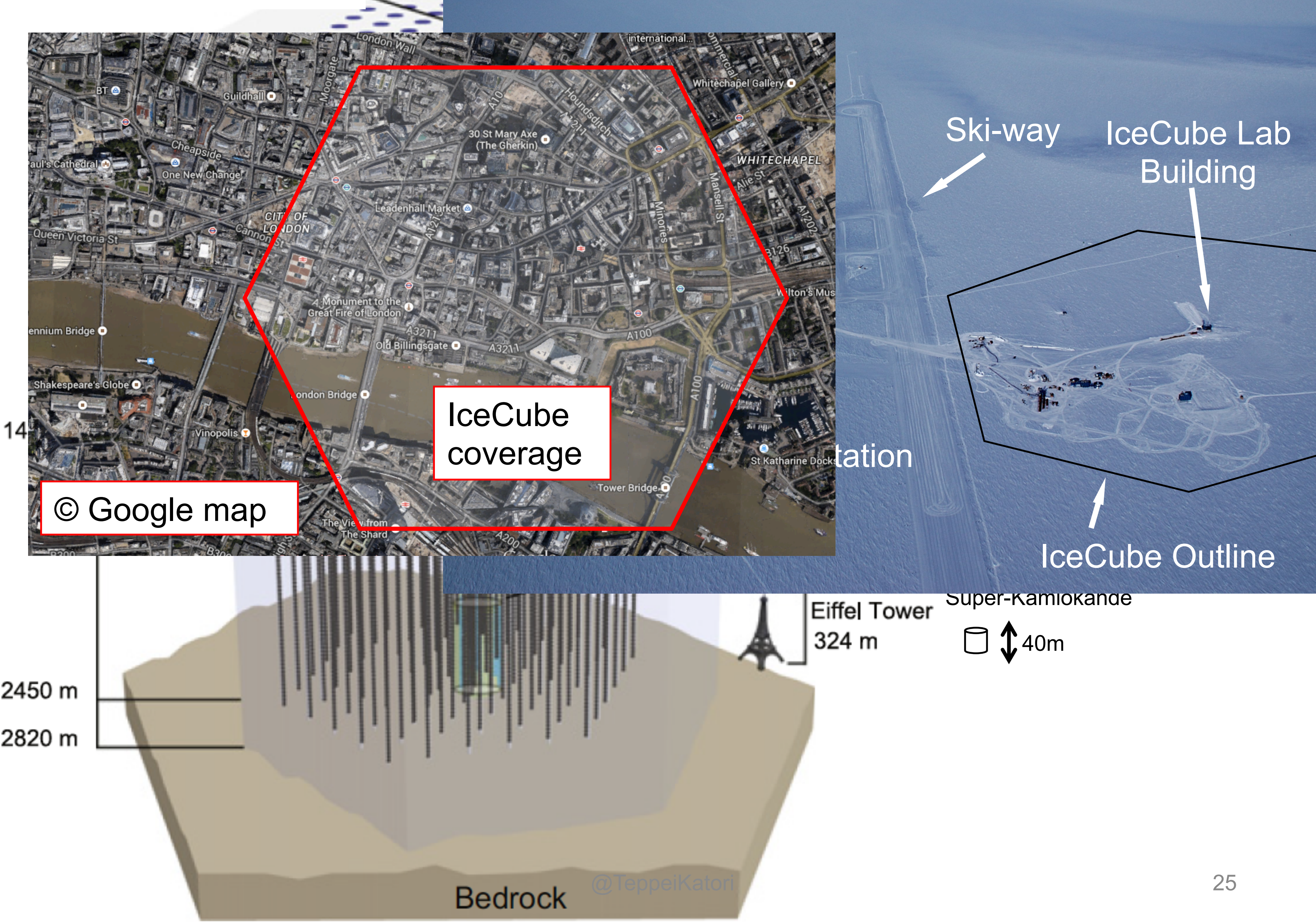

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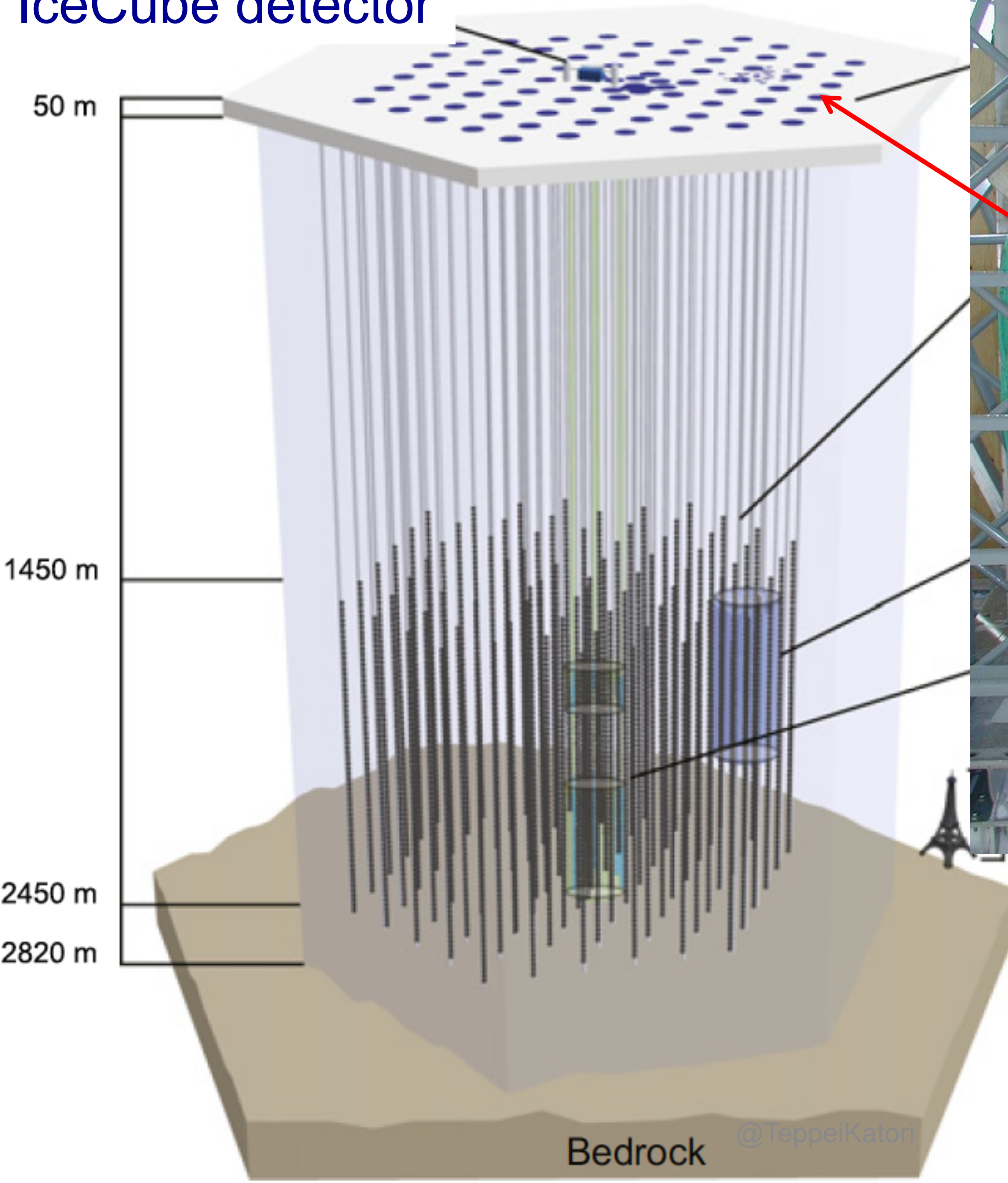
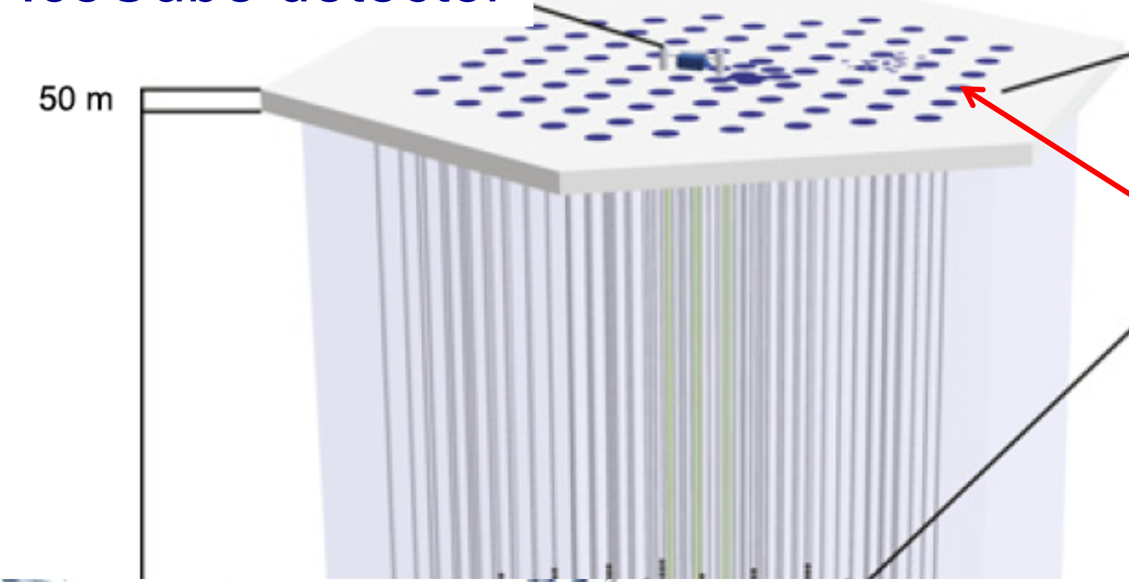
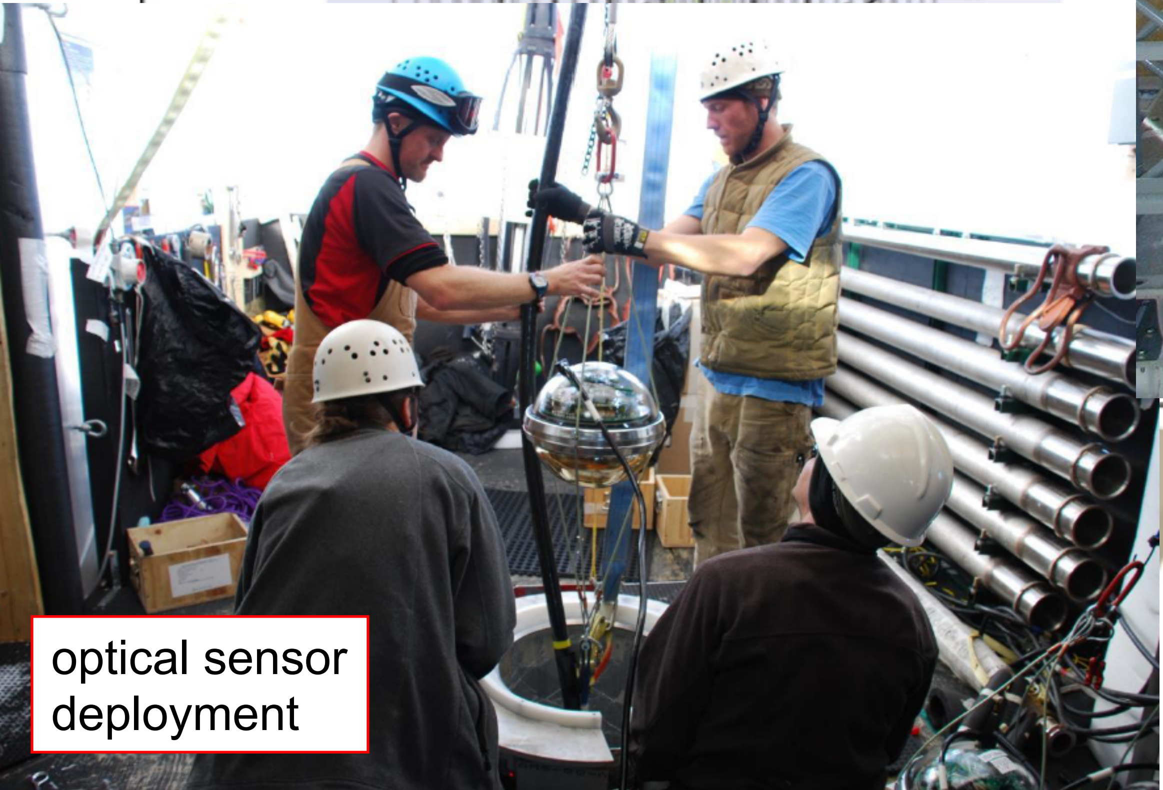


IceCube detector





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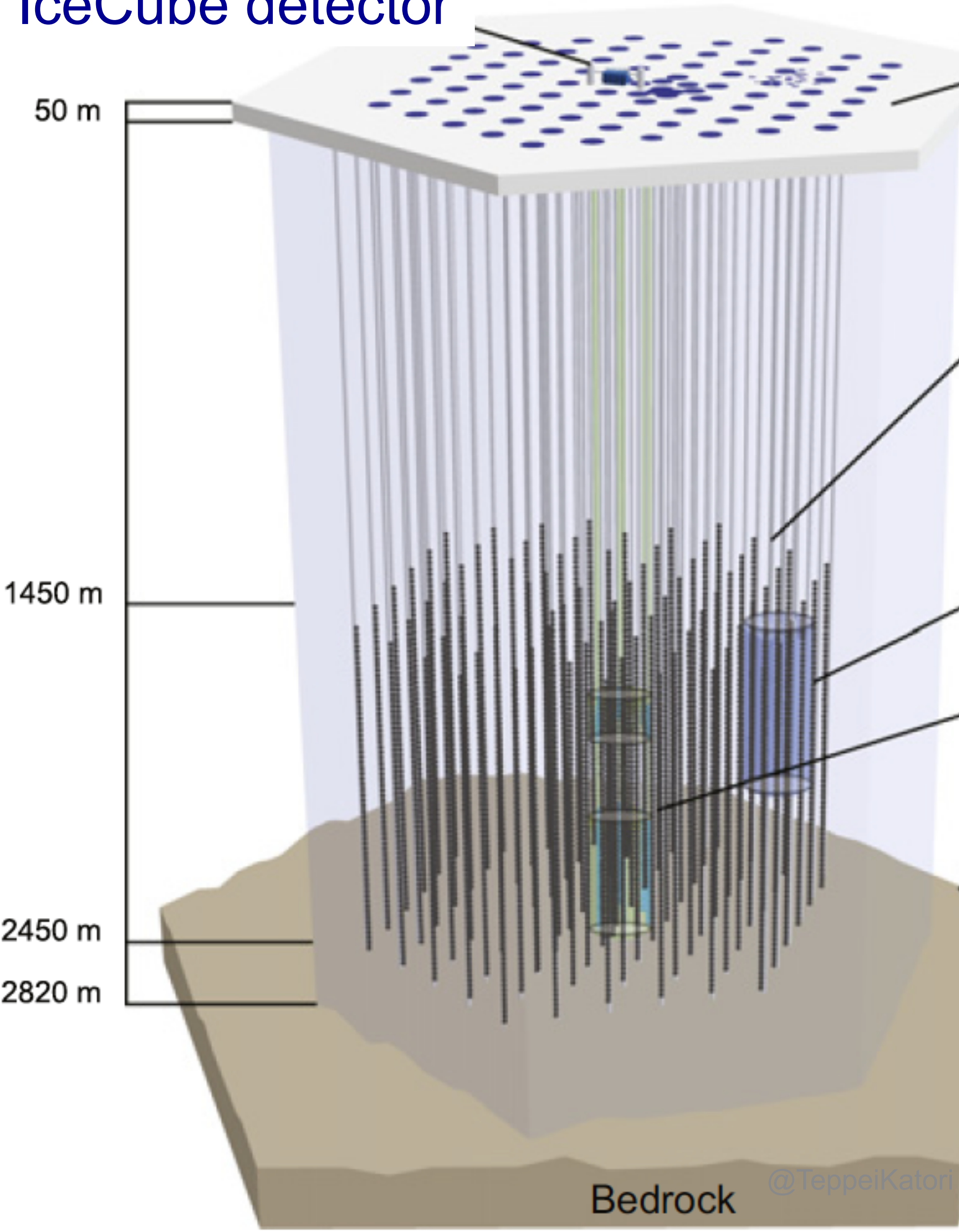
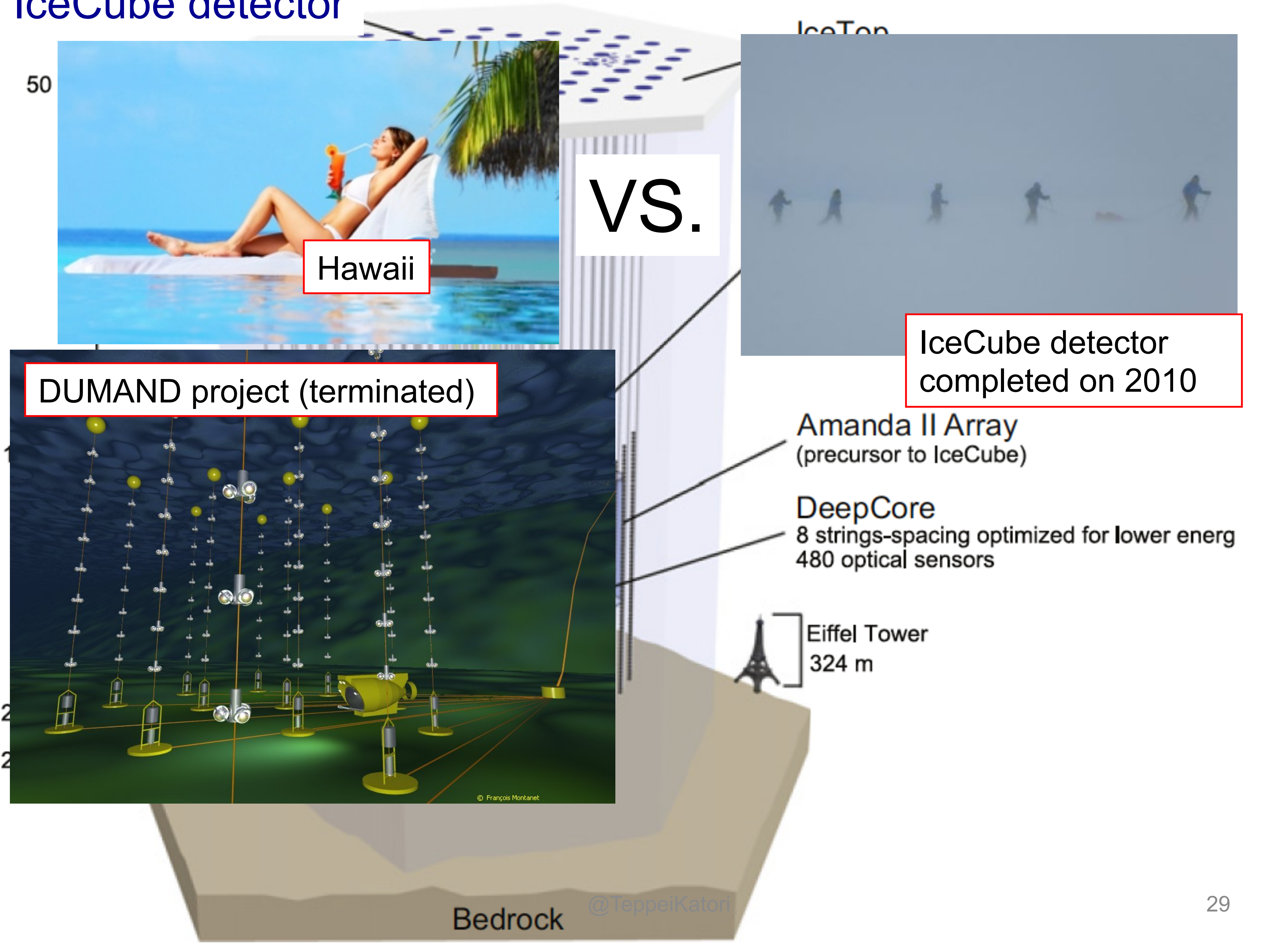
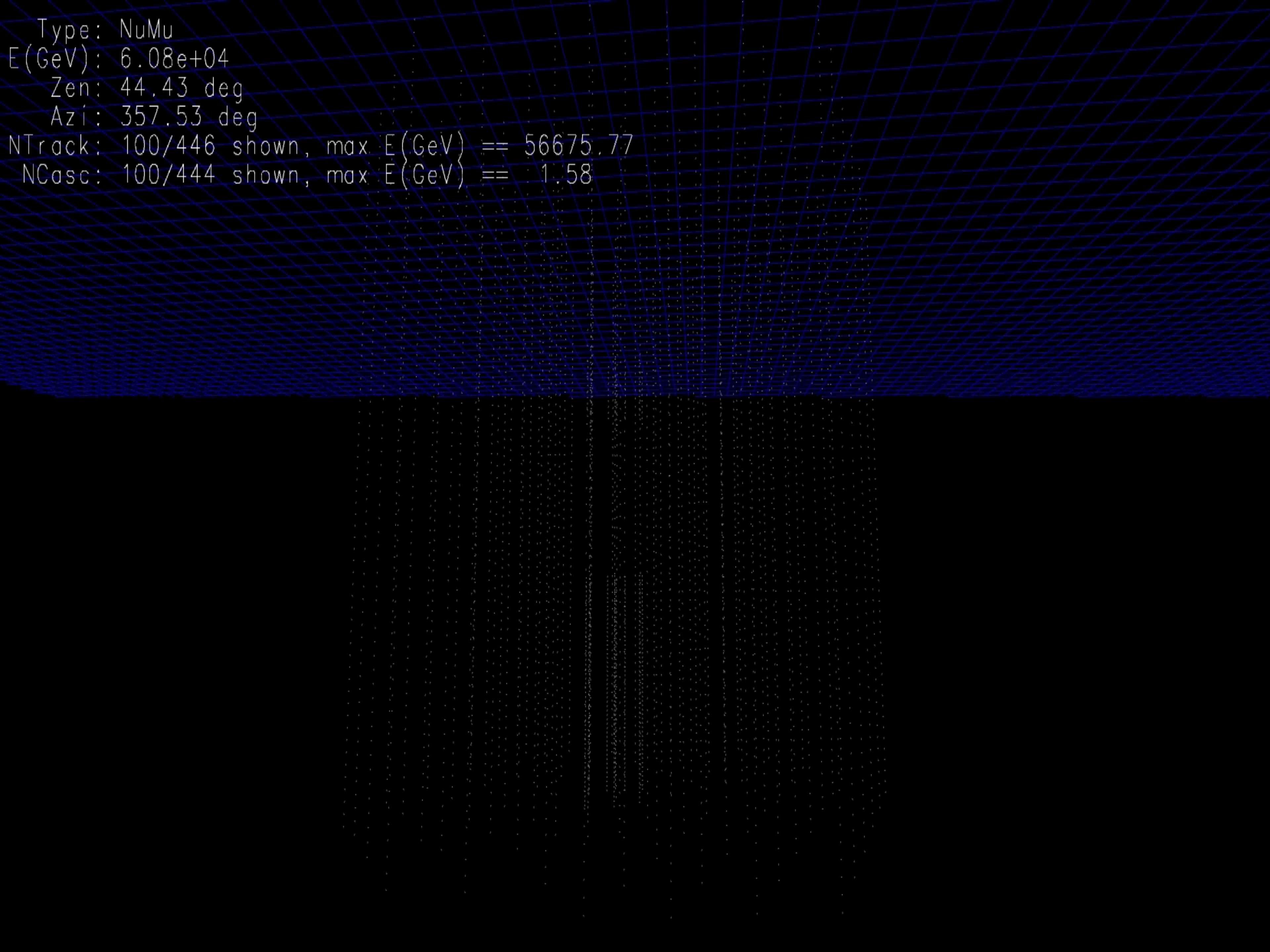


IceCube detector
completed on 2010

IceCube detector

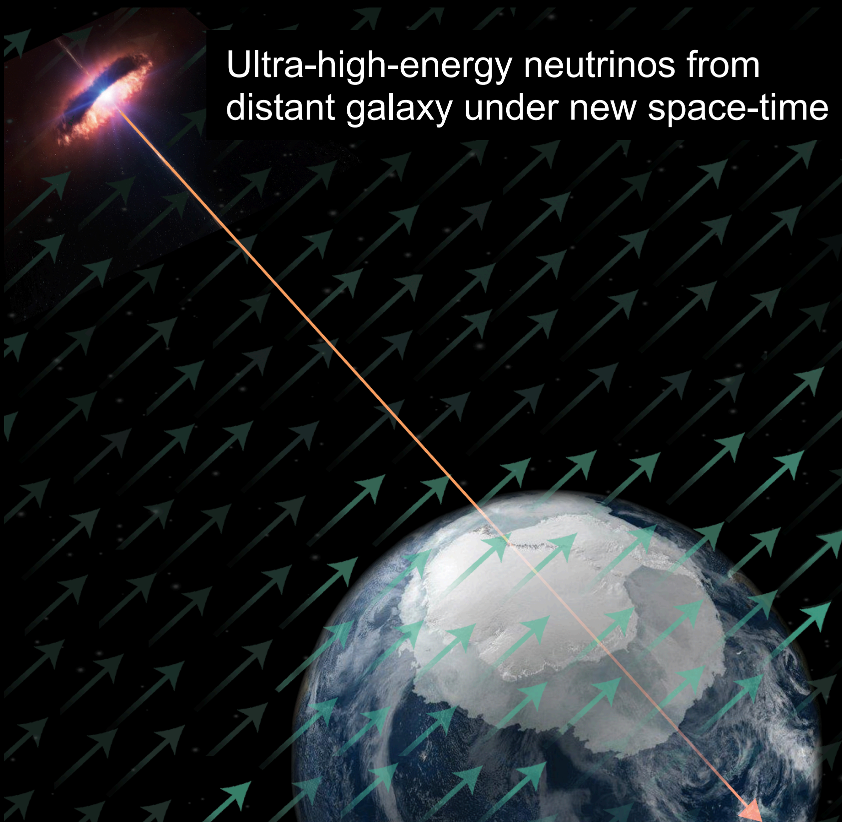



Type: NuMu
E(GeV): 6.08e+04
Zen: 44.43 deg
Azi: 357.53 deg
NTrack: 100/446 shown, max E(GeV) == 56675.77
NCasc: 100/444 shown, max E(GeV) == 1.58

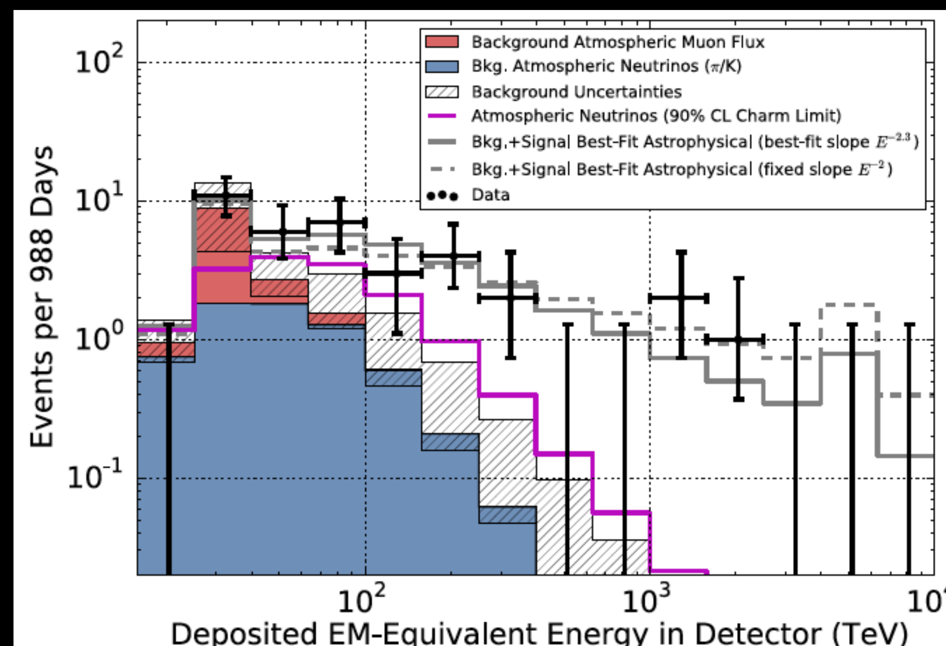
Discovery of Ultra-High-Energy Astrophysical Neutrinos

60 TeV to 2000 TeV high energy neutrinos (Large Hadron Collider ~ 7 TeV)

Analysis has been developed to look for Lorentz violation from astrophysical neutrino data



Measured high energy neutrino spectrum



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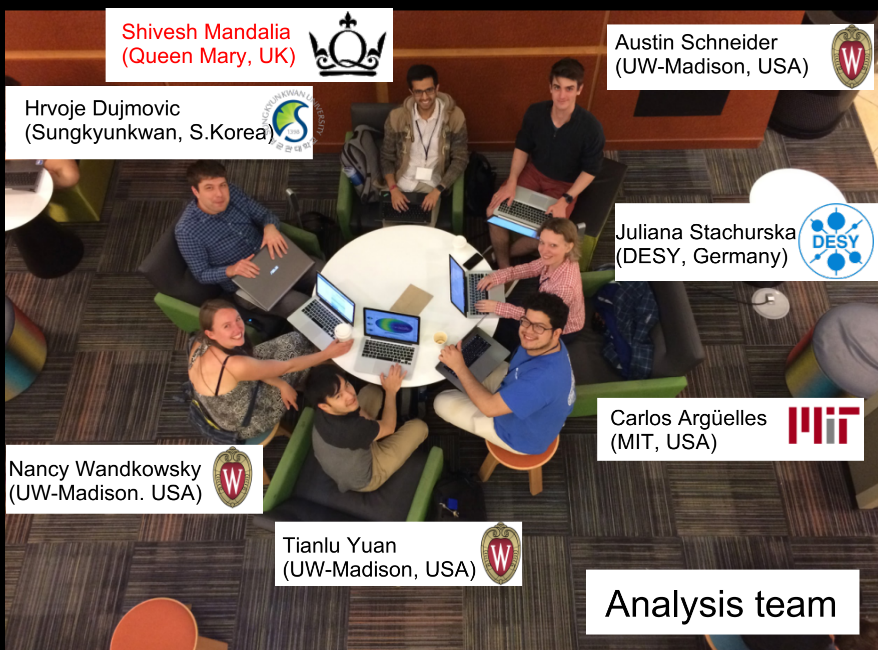

Shivesh (Queen Mary) is not quite satisfied with the result…

Queen Mary
University of London

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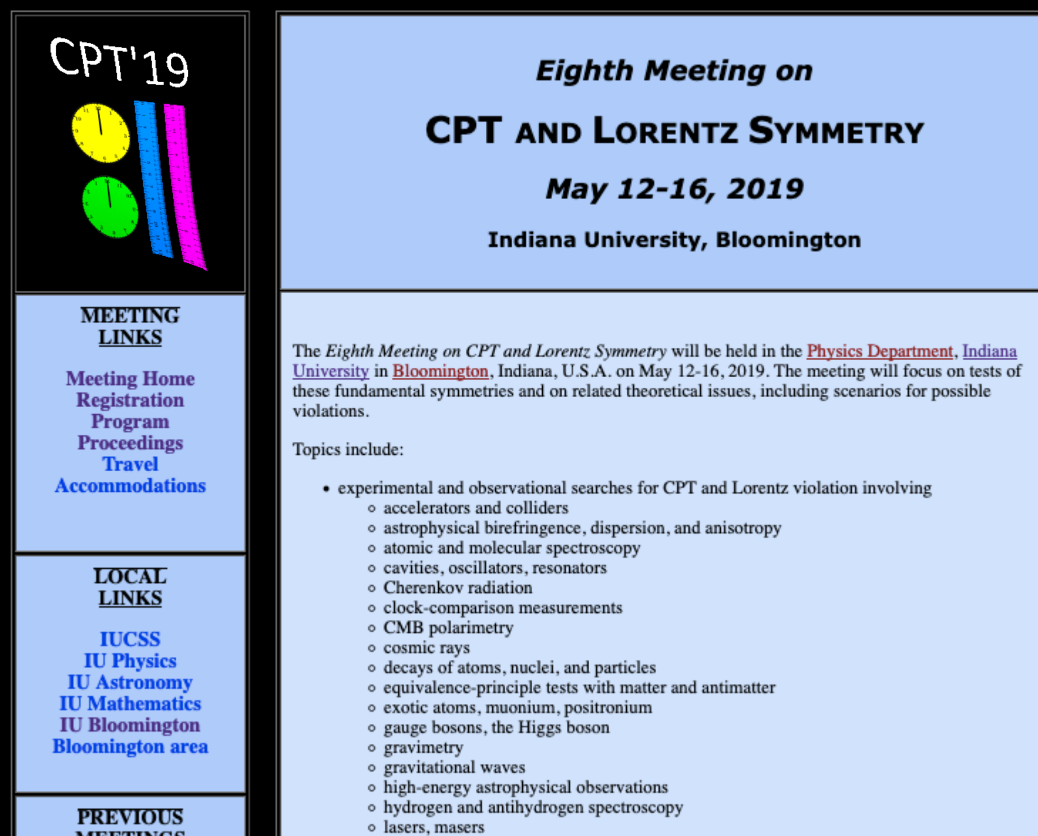
Why no Lorentz violation???


CPT'19

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IU Astronomy
IU Mathematics
IU Bloomington
Bloomington area

PREVIOUS MEETINGS

Eighth Meeting on

CPT AND LORENTZ SYMMETRY

May 12-16, 2019

Indiana University, Bloomington

The *Eighth Meeting on CPT and Lorentz Symmetry* will be held in the Physics Department, Indiana University in Bloomington, Indiana, U.S.A. on May 12-16, 2019. The meeting will focus on tests of these fundamental symmetries and on related theoretical issues, including scenarios for possible violations.

Topics include:

- experimental and observational searches for CPT and Lorentz violation involving
  - accelerators and colliders
  - astrophysical birefringence, dispersion, and anisotropy
  - atomic and molecular spectroscopy
  - cavities, oscillators, resonators
  - Cherenkov radiation
  - clock-comparison measurements
  - CMB polarimetry
  - cosmic rays
  - decays of atoms, nuclei, and particles
  - equivalence-principle tests with matter and antimatter
  - exotic atoms, muonium, positronium
  - gauge bosons, the Higgs boson
  - gravimetry
  - gravitational waves
  - high-energy astrophysical observations
  - hydrogen and antihydrogen spectroscopy
  - lasers, masers

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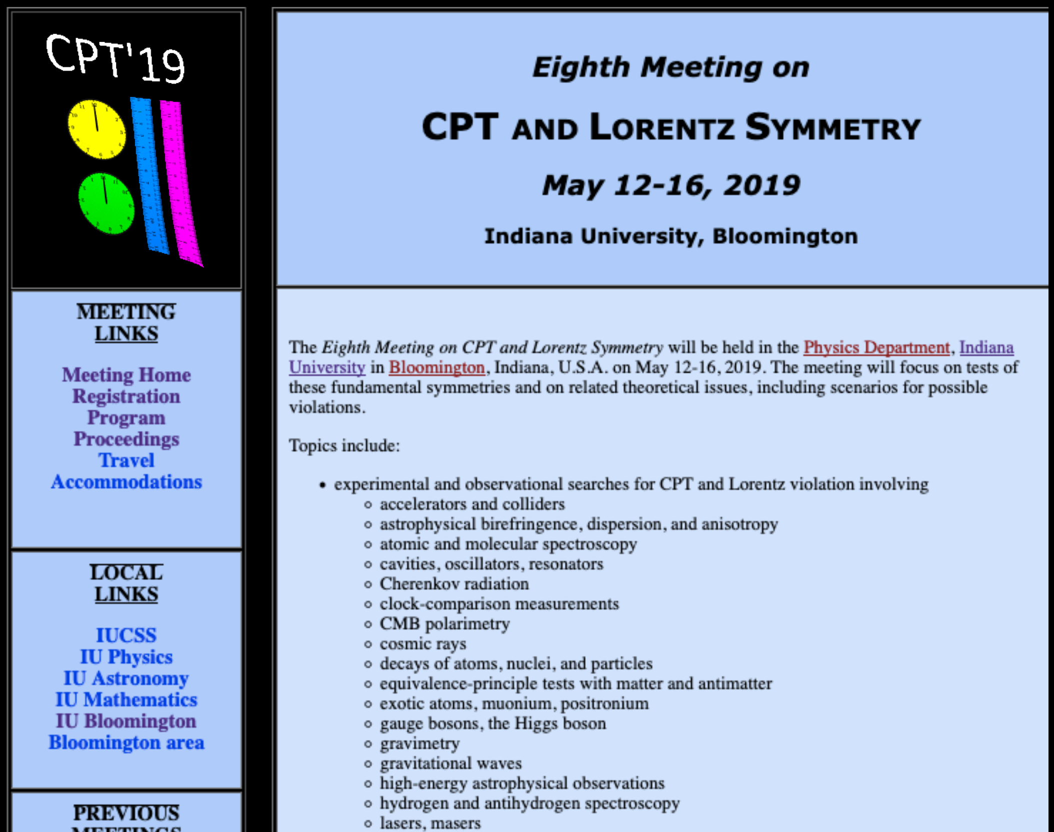
Einstein is just right.



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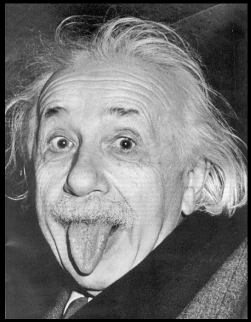
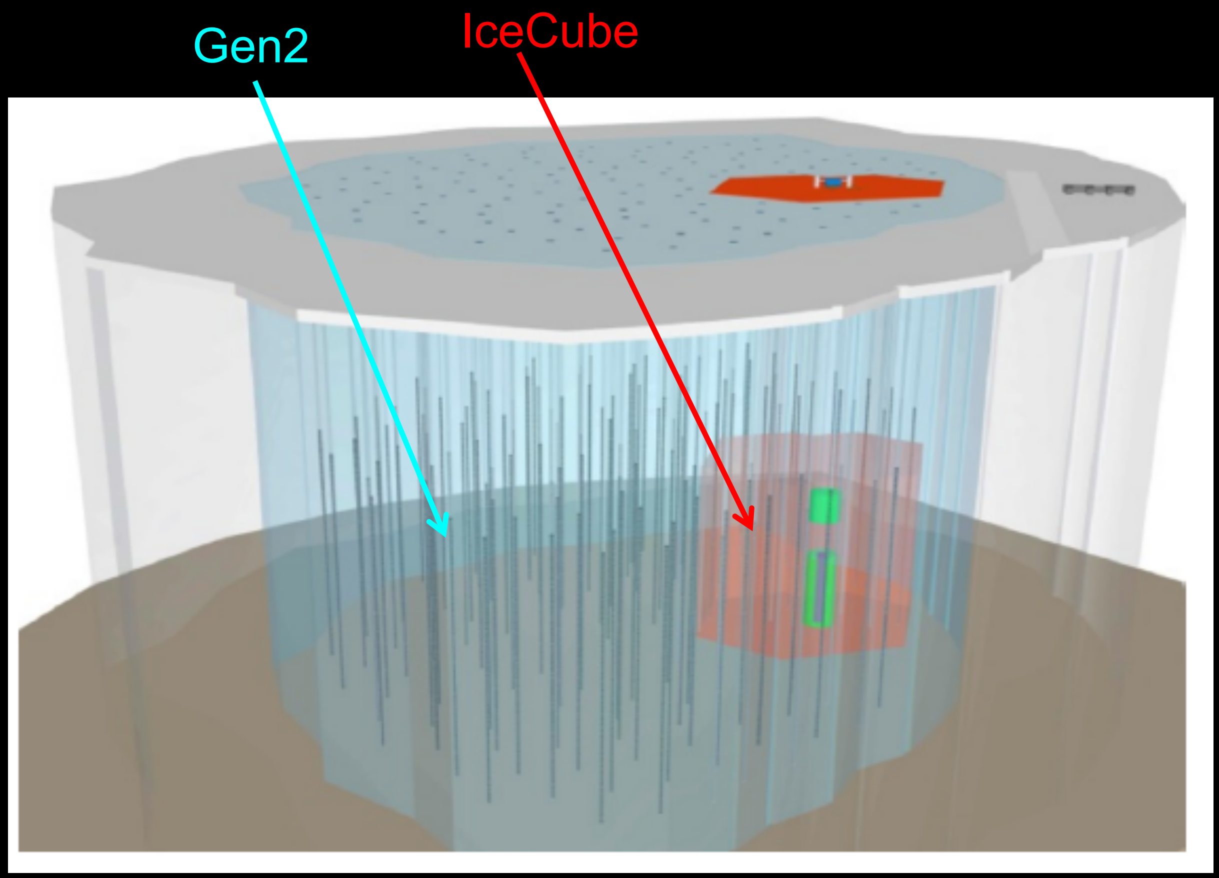


2. We need a better detector and better simulation, and more advanced analysis!

IceCube-Generation 2 (Gen2)



IceCube is too small.

To study astrophysical neutrinos more carefully, we need a bigger IceCube

Gen2
10 times bigger than IceCube.

UK members: Queen Mary, Manchester, Oxford, UCL

IceCube-Generation 2 (Gen2)

IceCube-Gen2 collaboration meeting (May 1, 2015)

IceCube is too small.

To study astrophysical neutrinos more carefully, we need a bigger IceCube

Gen2

10 times bigger than IceCube.

Project has been started with the biggest ever scale!

UK members: Queen Mary, Manchester, Oxford, UCL

Queen Mary University of London

Conclusion

Lorentz violation may be the first evidence of Theory of Everything

There is a worldwide effort to look for Lorentz violation, using various state-of-the-art techniques, but so far nobody found Lorentz violation

Ultra-high-energy astrophysical neutrinos have a great potential to discover Lorentz violation.The ultimate search of Lorentz violation has just begun, the effort to fulfill Hawking's dream continues…

Contact: KATORI@FNAL.GOV
Twitter: @teppeikatori

Thank you for your attention!