

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

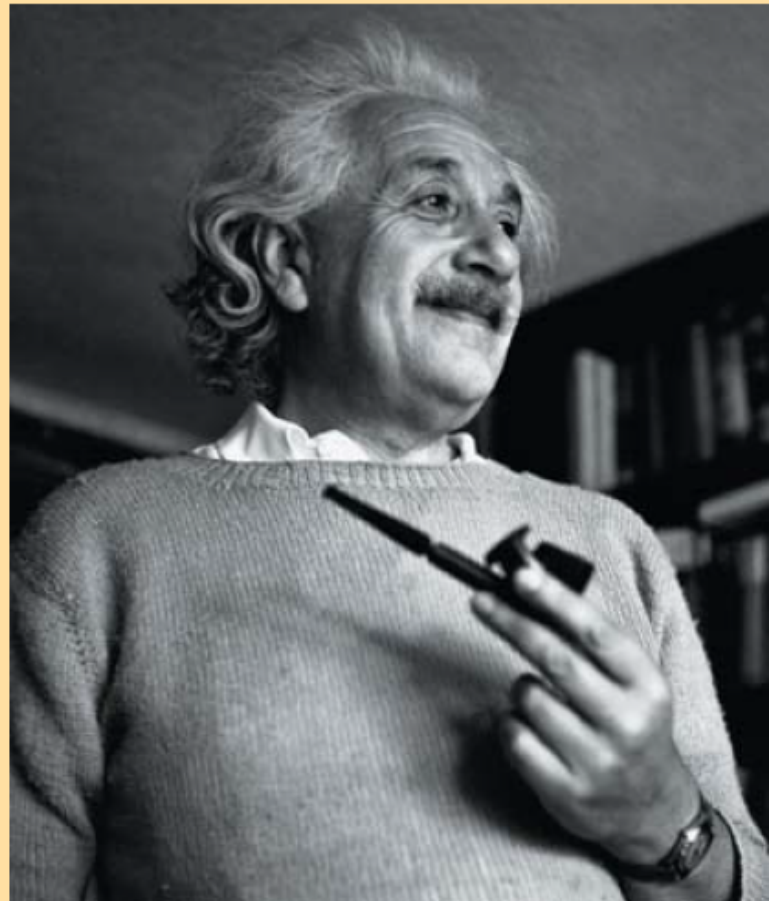
ICONOCLASTS

Toppling the Giant

Everyone wants to get a piece of Einstein. Two of the three most

artists and science
unified theory
is to have proved his
is: perpetual-motion
cannibals seeking the
misguided amateurs seem
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disprove is their own

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nni Amelino-Camelia of
r by Lee Smolin of the
n Ontario, João Magueijo



The cover of Scientific American magazine, September 2004, Special Issue. The title "SCIENTIFIC AMERICAN" is in large red letters at the top. Below it, "SPECIAL ISSUE" is written in yellow. The main title "BEYOND EINSTEIN" is in large white letters. A portrait of Albert Einstein is the central focus. Text on the cover includes: "For a century, his ideas have reshaped the world. But discover how physicists are now venturing beyond Einstein." and a list of topics: "Toward a Theory of Everything", "Energy That Expands the Cosmos", "Different Physics, Infinite Universes", "Does the Speed of Light Change?", "Computing with Relativity", "Einstein vs. Newton", and "And More ...".

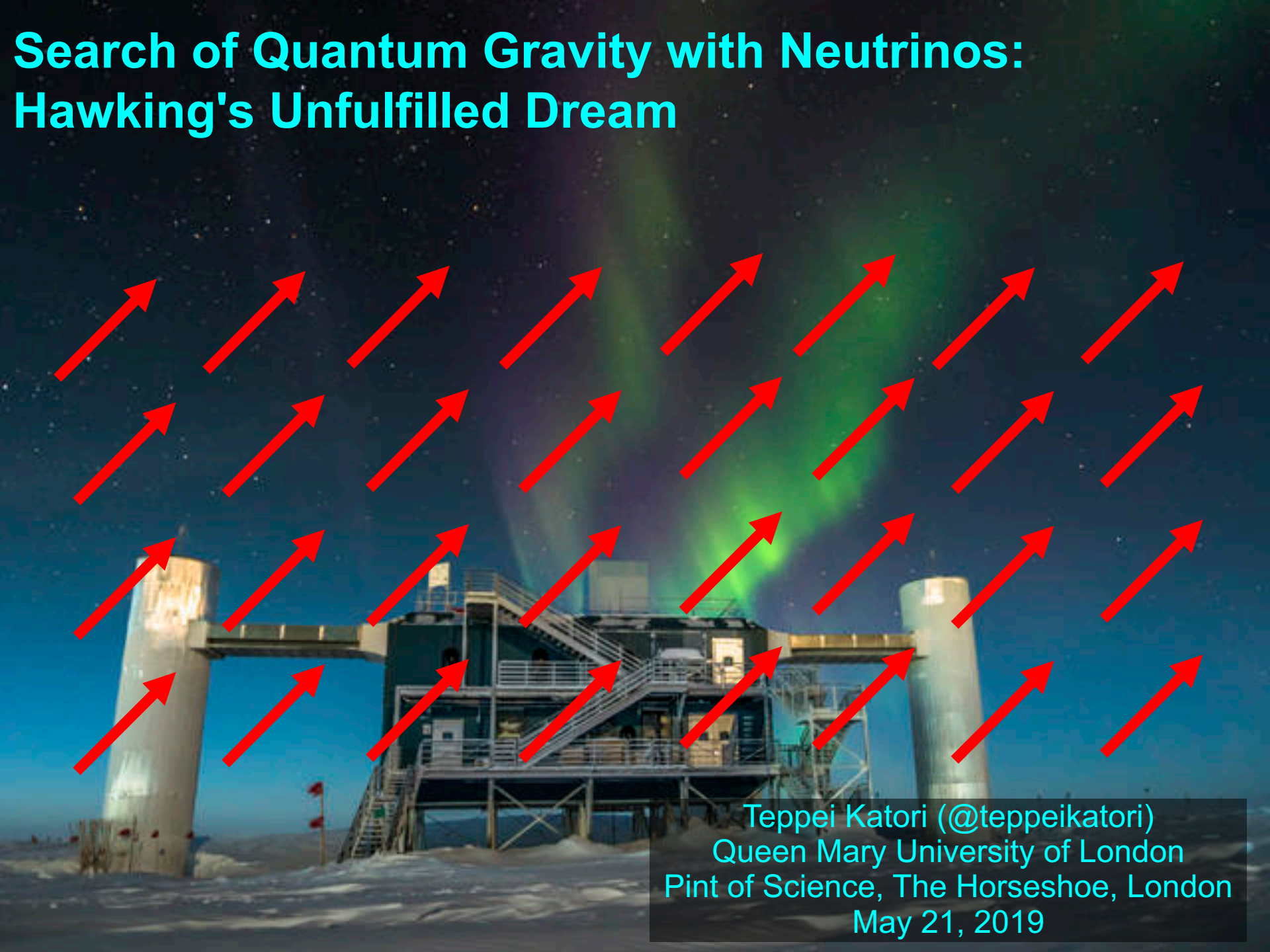
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May 21, 2019

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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

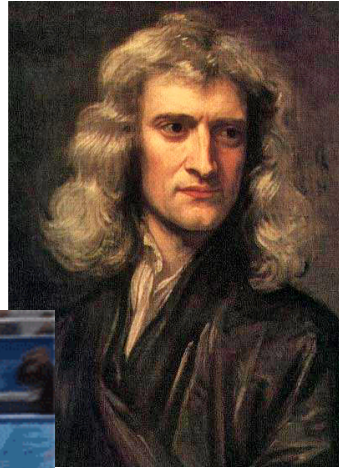


Conservation of Angular Momentum

Rotating objects keep rotating

Conservation of
angular momentum

Isaac Newton



Yulia Lipnitskaya (Russia)

Conservation of Angular Momentum

Rotating objects keep rotating

Conservation of angular momentum



Yulia Lipnitskaya (Russia)

Emmy Noether



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



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



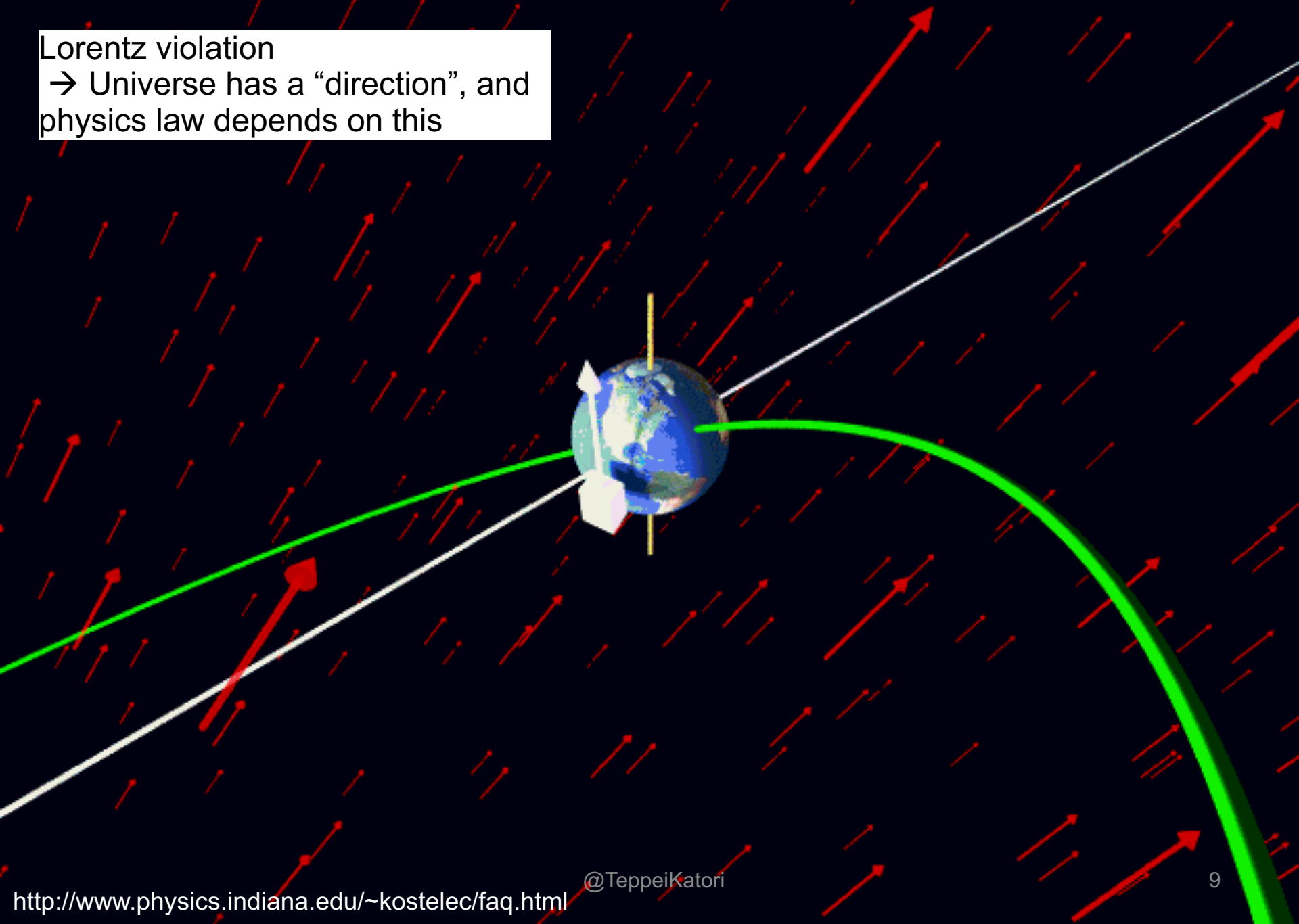
Stephen Hawking imposter and someone

I am even happier!



Lorentz violation

→ Universe has a “direction”, and physics law depends on this

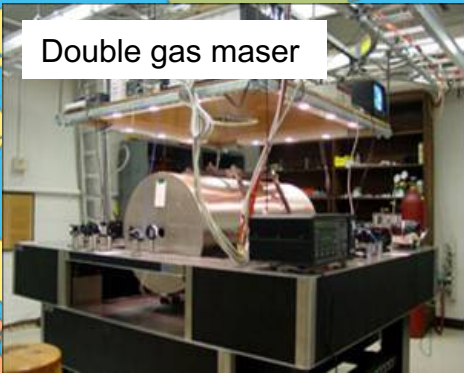


The race to defeat Einstein

Most precise something

Most precise magnetic field measurement

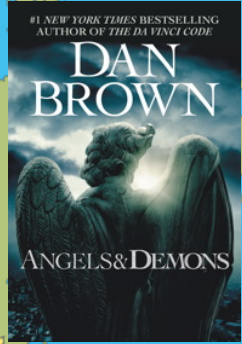
Largest amount of anti-hydrogen



Double gas maser



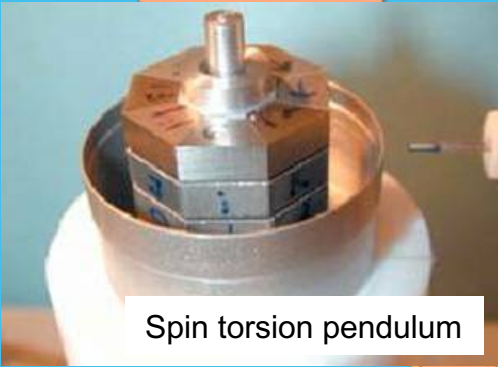
CERN



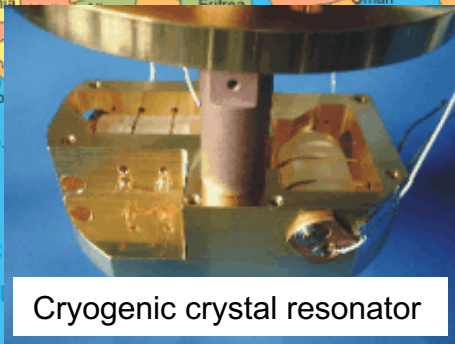
#1 NEW YORK TIMES BESTSELLING AUTHOR OF THE DA VINCI CODE

DAN BROWN

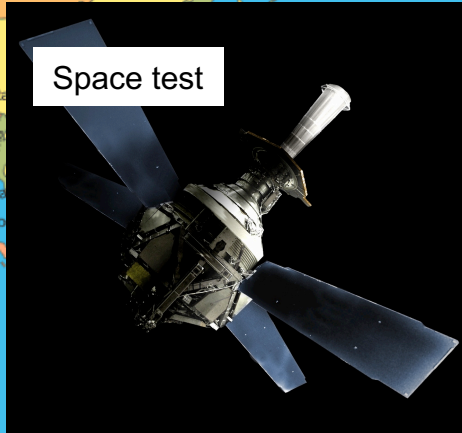
ANGELS & DEMONS



Spin torsion pendulum



Cryogenic crystal resonator



Space test

Most precise pendulum

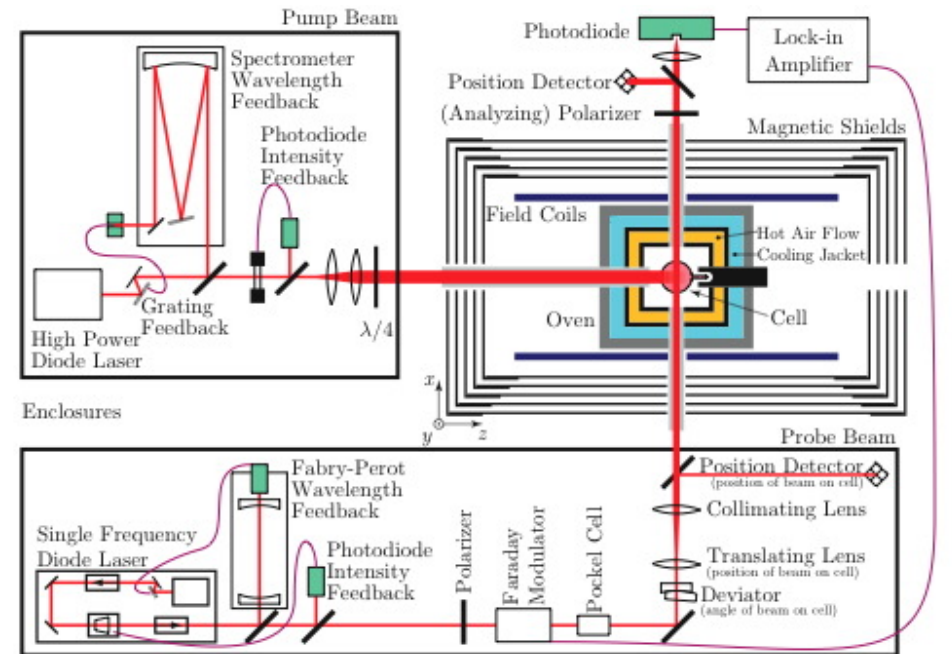
Most precise gyroscope

Most precise speed of light measurement

Double Noble Gas Maser

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

→ Lorentz violation is not discovered



Double Noble Gas Maser

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

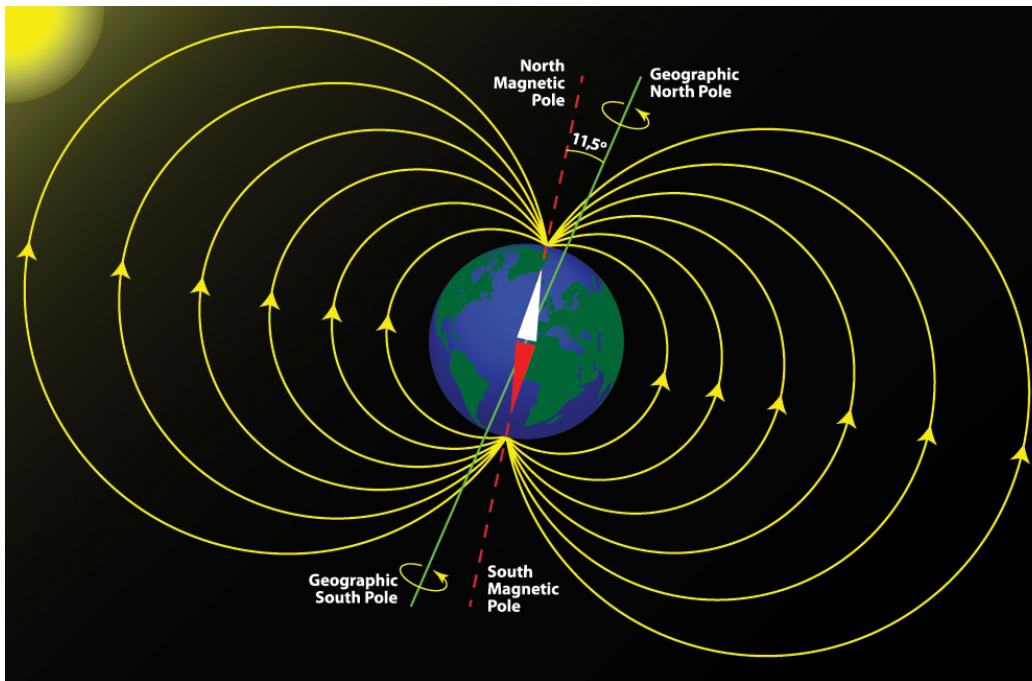
→ Lorentz violation is not discovered

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



Double Noble Gas Maser

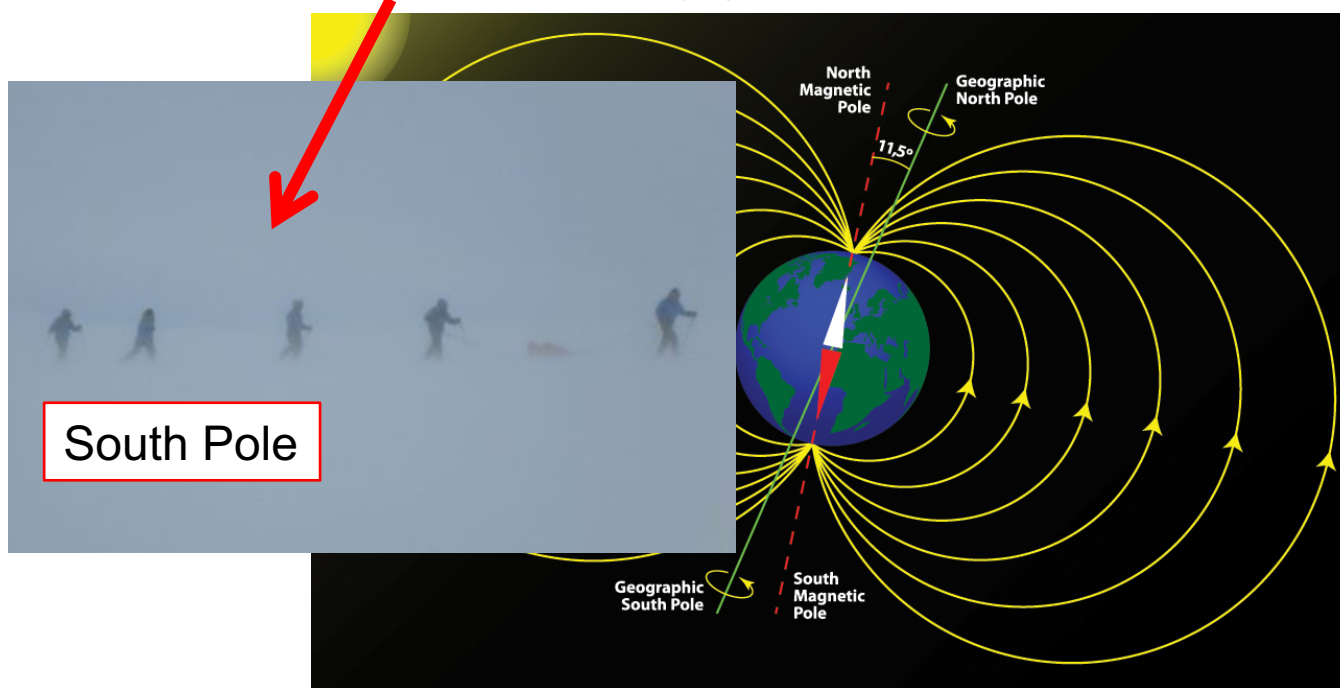
A type of atomic clock very sensitive to a tiny magnetic field

→ 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



Double Noble Gas Maser

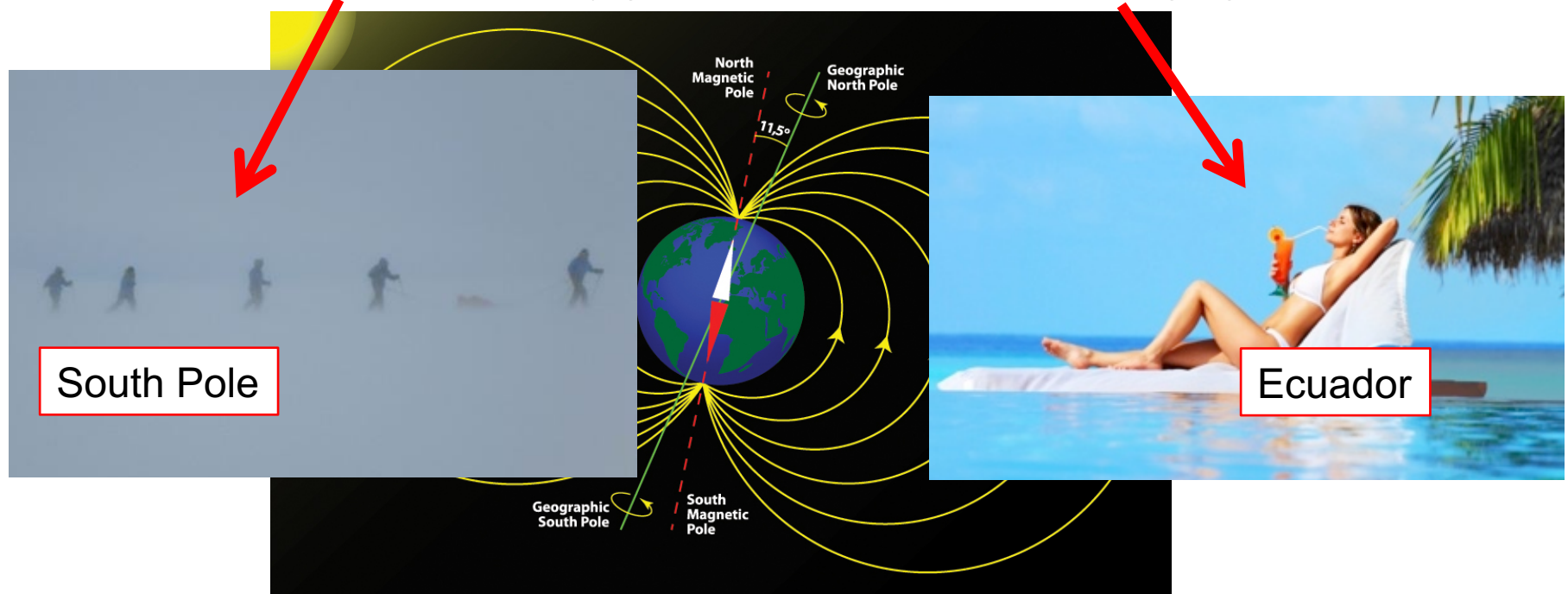
A type of atomic clock very sensitive to a tiny magnetic field

→ 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



The race to defeat Einstein

Most precise something



The race to defeat Einstein

Most precise something



Table S2. Maximal sensitivities for the photon sector

Coefficient	Electron	Proton
\tilde{b}_X	10^{-31} GeV	10^{-33}
\tilde{b}_Y	10^{-31} GeV	10^{-33}
\tilde{b}_Z	10^{-29} GeV	10^{-28}
\tilde{b}_T	10^{-26} GeV	10^{-7}
$\tilde{b}_J, (J = X, Y, Z)$	10^{-22} GeV	
\tilde{c}_-	10^{-20} GeV	10^{-24}
\tilde{c}_Q	10^{-17} GeV	10^{-21}
\tilde{c}_X	10^{-21} GeV	10^{-25}
\tilde{c}_Y	10^{-21} GeV	10^{-25}
\tilde{c}_Z	10^{-20} GeV	10^{-24}
\tilde{c}_{TX}	10^{-18} GeV	10^{-20}
\tilde{c}_{TY}	10^{-18} GeV	10^{-20}
\tilde{c}_{TZ}	10^{-20} GeV	10^{-20}
\tilde{c}_{TT}	10^{-18} GeV	10^{-11}
\tilde{d}_+	10^{-27} GeV	10^{-7}
\tilde{d}_-	10^{-26} GeV	
\tilde{d}_Q	10^{-26} GeV	10^{-7}
\tilde{d}_{XY}	10^{-26} GeV	
\tilde{d}_{YZ}	10^{-26} GeV	
\tilde{d}_{ZX}	10^{-26} GeV	
\tilde{d}_X	10^{-22} GeV	10^{-27} GeV
\tilde{d}_Y	10^{-22} GeV	10^{-27} GeV
\tilde{d}_Z	10^{-19} GeV	
\tilde{H}_{XT}	10^{-26} GeV	
\tilde{H}_{YT}	10^{-26} GeV	
\tilde{H}_{ZT}	10^{-26} GeV	
\tilde{g}_T	10^{-27} GeV	10^{-7} GeV
\tilde{g}_c	10^{-26} GeV	
\tilde{g}_Q		
\tilde{g}_-		
$\tilde{g}_{TJ}, (J = X, Y, Z)$		
\tilde{g}_{XY}	10^{-17} GeV	
\tilde{g}_{YX}	10^{-17} GeV	
\tilde{g}_{ZX}	10^{-18} GeV	
\tilde{g}_{XZ}	10^{-17} GeV	
\tilde{g}_{YZ}	10^{-17} GeV	
\tilde{g}_{ZY}	10^{-18} GeV	
\tilde{g}_{DX}	10^{-22} GeV	10^{-27} GeV
\tilde{g}_{DY}	10^{-22} GeV	10^{-27} GeV
\tilde{g}_{DZ}	10^{-22} GeV	

Table S3. Maximal sensitivities for the photon sector

$d = 3$	Coefficient	Sensitivity
	$k_{(V)00}^{(2)}$	10^{-43} GeV
	$k_{(V)10}^{(2)}$	10^{-42} GeV
	$\text{Re} k_{(V)11}^{(2)}$	10^{-42} GeV
	$\text{Im} k_{(V)11}^{(2)}$	10^{-42} GeV

$d = 4$	Coefficient	Sensitivity	Coefficient	Sensitivity
	$(\tilde{\kappa}_{e+})^{XY}$	10^{-32}	$(\tilde{\kappa}_{e-})^{XY}$	10^{-17}
	$(\tilde{\kappa}_{e+})^{XZ}$	10^{-32}	$(\tilde{\kappa}_{e-})^{XZ}$	10^{-17}
	$(\tilde{\kappa}_{e+})^{YZ}$	10^{-32}	$(\tilde{\kappa}_{e-})^{YZ}$	10^{-17}
	$(\tilde{\kappa}_{e+})^{XX} - (\tilde{\kappa}_{e+})^{YY}$	10^{-32}	$(\tilde{\kappa}_{e-})^{XX} - (\tilde{\kappa}_{e-})^{YY}$	10^{-17}
	$(\tilde{\kappa}_{e+})^{ZZ}$	10^{-32}	$(\tilde{\kappa}_{e-})^{ZZ}$	10^{-16}
	$(\tilde{\kappa}_{e-})^{XY}$	10^{-32}	$(\tilde{\kappa}_{o+})^{XY}$	10^{-13}
	$(\tilde{\kappa}_{e-})^{XZ}$	10^{-32}	$(\tilde{\kappa}_{o+})^{XZ}$	10^{-14}
	$(\tilde{\kappa}_{e-})^{YZ}$	10^{-32}	$(\tilde{\kappa}_{o+})^{YZ}$	10^{-14}
	$(\tilde{\kappa}_{e-})^{XX} - (\tilde{\kappa}_{e-})^{YY}$	10^{-32}		
	$(\tilde{\kappa}_{e-})^{ZZ}$	10^{-32}	$\tilde{\kappa}_{et}$	10^{-14}

Table S4. Maximal sensitivities for the neutrino

$d = 3$	Coefficient	$e\mu$	$e\tau$	$\mu\tau$	Coeff
	$\text{Re}(a_L)^T$	10^{-20} GeV	10^{-19} GeV	-	$\text{Im}(a_L)$
	$\text{Re}(a_L)^X$	10^{-20} GeV	10^{-19} GeV	10^{-23} GeV	$\text{Im}(a_L)$
	$\text{Re}(a_L)^Y$	10^{-21} GeV	10^{-19} GeV	10^{-23} GeV	$\text{Im}(a_L)$
	$\text{Re}(a_L)^Z$	10^{-19} GeV	10^{-19} GeV	-	$\text{Im}(a_L)$

$d = 4$	Coefficient	$e\mu$	$e\tau$	$\mu\tau$	Coefficient	$e\mu$	$e\tau$	$\mu\tau$
	$\text{Re}(c_L)^{XY}$	10^{-21}	10^{-17}	10^{-23}	$\text{Im}(c_L)^{XY}$	10^{-21}	10^{-17}	10^{-21}
	$\text{Re}(c_L)^{XZ}$	10^{-21}	10^{-17}	10^{-23}	$\text{Im}(c_L)^{XZ}$	10^{-21}	10^{-17}	10^{-21}
	$\text{Re}(c_L)^{YZ}$	10^{-21}	10^{-16}	10^{-23}	$\text{Im}(c_L)^{YZ}$	10^{-21}	10^{-16}	10^{-21}
	$\text{Re}(c_L)^{XX}$	10^{-21}	10^{-16}	10^{-23}	$\text{Im}(c_L)^{XX}$	10^{-21}	10^{-16}	10^{-21}
	$\text{Re}(c_L)^{YY}$	10^{-21}	10^{-16}	10^{-23}	$\text{Im}(c_L)^{YY}$	10^{-21}	10^{-16}	10^{-21}
	$\text{Re}(c_L)^{ZZ}$	10^{-19}	10^{-16}	-	$\text{Im}(c_L)^{ZZ}$	-	10^{-16}	-
	$\text{Re}(c_L)^{TT}$	10^{-19}	10^{-17}	-	$\text{Im}(c_L)^{TT}$	-	10^{-17}	-
	$\text{Re}(c_L)^{TX}$	10^{-22}	10^{-17}	10^{-27}	$\text{Im}(c_L)^{TX}$	10^{-22}	10^{-17}	10^{-22}
	$\text{Re}(c_L)^{TY}$	10^{-22}	10^{-17}	10^{-27}	$\text{Im}(c_L)^{TY}$	10^{-22}	10^{-17}	10^{-22}
	$\text{Re}(c_L)^{TZ}$	10^{-20}	10^{-16}	-	$\text{Im}(c_L)^{TZ}$	-	10^{-16}	-

Isotropic	Coefficient	Sensitivity	Coefficient	Sensitivity
	$\tilde{a}_{\mu\mu}^{(2)}$	10^{-7} GeV	$\tilde{a}_{\mu\mu}^{(2)}$	10^{-20} GeV
	$\tilde{c}_{\mu\mu}^{(4)}$	10^{-9}	$\tilde{c}_{\mu\mu}^{(4)}$	10^{-10}
	$\tilde{a}_{\mu\mu}^{(5)}$	10^{-18} GeV ⁻¹	$\tilde{a}_{\mu\mu}^{(5)}$	10^{-19} GeV ⁻¹
	$\tilde{c}_{\mu\mu}^{(6)}$	10^{-9} GeV ⁻²	$\tilde{c}_{\mu\mu}^{(6)}$	10^{-19} GeV ⁻²
	$\tilde{a}_{\mu\mu}^{(7)}$	10^{-29} GeV ⁻³	$\tilde{a}_{\mu\mu}^{(7)}$	10^{-19} GeV ⁻³
	$\tilde{c}_{\mu\mu}^{(8)}$	10^{-11} GeV ⁻⁴	$\tilde{c}_{\mu\mu}^{(8)}$	10^{-18} GeV ⁻⁴
	$\tilde{a}_{\mu\mu}^{(9)}$	10^{-40} GeV ⁻⁵	$\tilde{a}_{\mu\mu}^{(9)}$	10^{-18} GeV ⁻⁵
	$\tilde{c}_{\mu\mu}^{(10)}$	10^{-14} GeV ⁻⁶	$\tilde{c}_{\mu\mu}^{(10)}$	10^{-18} GeV ⁻⁶

Table D6. Electron sector, $d = 3, 4$ (part 1 of 3)

Combination	Result	System	Ref.
$ b_0 $	$< 2 \times 10^{-14}$ GeV	Cs spectroscopy	[30]*, [31]*
"	$< 2 \times 10^{-12}$ GeV	Tl spectroscopy	[30]*, [31]*
"	$< 7 \times 10^{-15}$ GeV	Dry spectroscopy	[30]*, [31]*

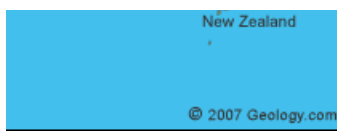
Table D6. Electron sector, $d = 3, 4$ (part 2 of 3)

Combination	Result	System	Ref.
$\tilde{c}^{UR(4)}$	$< 1.5 \times 10^{-15}$	Astrophysics	[41]*, [18]*
"	$> -5 \times 10^{-13}$	"	[42]*, [18]*
"	$(-1.3 \text{ to } 0.2) \times 10^{-15}$	"	[43]*, [18]*
"	$> -1.2 \times 10^{-16}$	"	[44]*, [18]*

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)

$-7 \text{ to } 4) \times 10^{-15}$	"	[58]*	$\times 10^{-9}$	"	[49]
$1 \text{ to } 1.5) \times 10^{-15}$	"	[58]*	$\times 10^{-9}$	"	[49]
$-4 \text{ to } 2) \times 10^{-17}$	"	[58]*	$\times 10^{-6}$	Nuclear binding energy	[50]
$< 1.3 \times 10^{-15}$	"	[59]*	$\times 10^{-6}$	Cs interferometer	[51]
	"		$\times 10^{-15}$	Collider physics	[52]*
	"		$\times 10^{-14}$	"	[52]*
$< 2.5 \times 10^{-15}$	"	[59]*	$\times 10^{-15}$	"	[52]*
	"		$\times 10^{-13}$	"	[52]*
	"		$\times 10^{-11}$	1S-2S transition	[53]*
$.8) \times 10^{-27}$ GeV	Torsion pendulum	[32]	$\times 10^{-16}$	Optical, microwave resonators	[54]*
$.4) \times 10^{-27}$ GeV	"	[32]	$\times 10^{-16}$	"	[54]*
$.9) \times 10^{-27}$ GeV	"	[32]	$\times 10^{-16}$	"	[54]*
$.2) \times 10^{-27}$ GeV	"	[32]	$\times 10^{-16}$	"	[54]*
$< 2 \times 10^{-14}$	Astrophysics	[60]*	$\times 10^{-16}$	"	[54]*
$< 3 \times 10^{-15}$	"	[60]*	$\times 10^{-16}$	"	[54]*
$< 2 \times 10^{-15}$	"	[60]*	$\times 10^{-16}$	"	[54]*
$< 2 \times 10^{-14}$	"	[60]*	$\times 10^{-16}$	"	[54]*
$< 7 \times 10^{-15}$	"	[60]*	$\times 10^{-16}$	"	[54]*
$< 5 \times 10^{-14}$	"	[60]*	$\times 10^{-16}$	"	[54]*
$< 5 \times 10^{-15}$	"	[60]*	$\times 10^{-16}$	"	[54]*
$< 8 \times 10^{-17}$	"	[60]*	$\times 10^{-16}$	"	[54]*
$< 10^{-22}$ GeV	Hg/Cs comparison	[39], [40]*			
$< 10^{-19}$ GeV	Astrophysics	[28]*			
$< 10^{-17}$ GeV	Astrophysics	[28]*			
$< 10^{-17}$ GeV	"	[28]*			
$< 10^{-18}$ GeV	"	[28]*			
$< 10^{-22}$ GeV	Penning trap	[28]*			
$< 10^{-22}$ GeV	Hg/Cs comparison	[39], [40]*			



So far no experiments find Lorentz violation...

most precise something

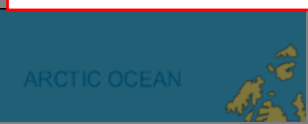


Table S2. Maximal sensitivities for the photon sector

Coefficient	Electron	Proton
\tilde{b}_X	10^{-31} GeV	10^{-33}
\tilde{b}_Y	10^{-31} GeV	10^{-33}
\tilde{b}_Z	10^{-29} GeV	10^{-28}
\tilde{b}_T	10^{-26} GeV	10^{-7}
$\tilde{b}_J, (J = X, Y, Z)$	10^{-22} GeV	
\tilde{c}_-	10^{-20} GeV	10^{-24}
\tilde{c}_Q	10^{-17} GeV	10^{-21}
\tilde{c}_X	10^{-21} GeV	10^{-25}
\tilde{c}_Y	10^{-21} GeV	10^{-25}
\tilde{c}_Z	10^{-20} GeV	10^{-24}
\tilde{c}_{TX}	10^{-18} GeV	10^{-20}
\tilde{c}_{TY}	10^{-18} GeV	10^{-20}
\tilde{c}_{TZ}	10^{-20} GeV	10^{-20}
\tilde{c}_{TT}	10^{-18} GeV	10^{-11}
\tilde{d}_+	10^{-27} GeV	10^{-7}
\tilde{d}_-	10^{-26} GeV	
\tilde{d}_Q	10^{-26} GeV	10^{-7}
\tilde{d}_{XY}	10^{-26} GeV	
\tilde{d}_{YZ}	10^{-26} GeV	
\tilde{d}_{ZX}	10^{-26} GeV	
\tilde{d}_X	10^{-22} GeV	10^{-27} GeV
\tilde{d}_Y	10^{-22} GeV	10^{-27} GeV
\tilde{d}_Z	10^{-19} GeV	
\tilde{H}_{XT}	10^{-26} GeV	
\tilde{H}_{YT}	10^{-26} GeV	
\tilde{H}_{ZT}	10^{-26} GeV	
\tilde{g}_T	10^{-27} GeV	10^{-7} GeV
\tilde{g}_c	10^{-26} GeV	
\tilde{g}_Q		
\tilde{g}_-		
$\tilde{g}_{TJ}, (J = X, Y, Z)$		
\tilde{g}_{XY}	10^{-17} GeV	
\tilde{g}_{YZ}	10^{-17} GeV	
\tilde{g}_{ZX}	10^{-18} GeV	
$\tilde{g}_X Z$	10^{-17} GeV	
$\tilde{g}_Y Z$	10^{-17} GeV	
\tilde{g}_{ZY}	10^{-18} GeV	
\tilde{g}_{DX}	10^{-22} GeV	10^{-27} GeV
\tilde{g}_{DY}	10^{-22} GeV	10^{-27} GeV
\tilde{g}_{DZ}	10^{-22} GeV	

Table S3. Maximal sensitivities for the photon sector

$d = 3$	Coefficient	Sensitivity
	$k_{(V)00}^{(3)}$	10^{-43} GeV
	$k_{(V)10}^{(3)}$	10^{-42} GeV
	$\text{Re } k_{(V)11}^{(3)}$	10^{-42} GeV
	$\text{Im } k_{(V)11}^{(3)}$	10^{-42} GeV

$d = 4$	Coefficient	Sensitivity	Coefficient	Sensitivity
	$(\tilde{\kappa}_{e+})^{XY}$	10^{-32}	$(\tilde{\kappa}_{e-})^{XY}$	10^{-17}
	$(\tilde{\kappa}_{e+})^{XZ}$	10^{-32}	$(\tilde{\kappa}_{e-})^{XZ}$	10^{-17}
	$(\tilde{\kappa}_{e+})^{YZ}$	10^{-32}	$(\tilde{\kappa}_{e-})^{YZ}$	10^{-17}
	$(\tilde{\kappa}_{e+})^{XX} - (\tilde{\kappa}_{e+})^{YY}$	10^{-32}	$(\tilde{\kappa}_{e-})^{XX} - (\tilde{\kappa}_{e-})^{YY}$	10^{-17}
	$(\tilde{\kappa}_{e+})^{ZZ}$	10^{-32}	$(\tilde{\kappa}_{e-})^{ZZ}$	10^{-16}
	$(\tilde{\kappa}_{o-})^{XY}$	10^{-32}	$(\tilde{\kappa}_{o+})^{XY}$	10^{-13}
	$(\tilde{\kappa}_{o-})^{XZ}$	10^{-32}	$(\tilde{\kappa}_{o+})^{XZ}$	10^{-14}
	$(\tilde{\kappa}_{o-})^{YZ}$	10^{-32}	$(\tilde{\kappa}_{o+})^{YZ}$	10^{-14}
	$(\tilde{\kappa}_{o-})^{XX} - (\tilde{\kappa}_{o-})^{YY}$	10^{-32}		
	$(\tilde{\kappa}_{o-})^{ZZ}$	10^{-32}	$\tilde{\kappa}_{st}$	10^{-14}

Table S4. Maximal sensitivities for the neutrino

$d = 3$	Coefficient	$e\mu$	$e\tau$	$\mu\tau$	Coeff
	$\text{Re}(a_L)^T$	10^{-20} GeV	10^{-19} GeV	-	$\text{Im}(a_L)$
	$\text{Re}(a_L)^X$	10^{-20} GeV	10^{-19} GeV	10^{-23} GeV	$\text{Im}(a_L)$
	$\text{Re}(a_L)^Y$	10^{-21} GeV	10^{-19} GeV	10^{-23} GeV	$\text{Im}(a_L)$
	$\text{Re}(a_L)^Z$	10^{-19} GeV	10^{-19} GeV	-	$\text{Im}(a_L)$

$d = 4$	Coefficient	$e\mu$	$e\tau$	$\mu\tau$	Coefficient	$e\mu$	$e\tau$	$\mu\tau$
	$\text{Re}(c_L)^{XY}$	10^{-21}	10^{-17}	10^{-23}	$\text{Im}(c_L)^{XY}$	10^{-21}	10^{-17}	10^{-21}
	$\text{Re}(c_L)^{XZ}$	10^{-21}	10^{-17}	10^{-23}	$\text{Im}(c_L)^{XZ}$	10^{-21}	10^{-17}	10^{-21}
	$\text{Re}(c_L)^{YZ}$	10^{-21}	10^{-16}	10^{-23}	$\text{Im}(c_L)^{YZ}$	10^{-21}	10^{-16}	10^{-21}
	$\text{Re}(c_L)^{XX}$	10^{-21}	10^{-16}	10^{-23}	$\text{Im}(c_L)^{XX}$	10^{-21}	10^{-16}	10^{-21}
	$\text{Re}(c_L)^{YY}$	10^{-21}	10^{-16}	10^{-23}	$\text{Im}(c_L)^{YY}$	10^{-21}	10^{-16}	10^{-21}
	$\text{Re}(c_L)^{ZZ}$	10^{-19}	10^{-16}	-	$\text{Im}(c_L)^{ZZ}$	-	10^{-16}	-
	$\text{Re}(c_L)^{TT}$	10^{-19}	10^{-17}	-	$\text{Im}(c_L)^{TT}$	-	10^{-17}	-
	$\text{Re}(c_L)^{TX}$	10^{-22}	10^{-17}	10^{-27}	$\text{Im}(c_L)^{TX}$	10^{-22}	10^{-17}	10^{-22}
	$\text{Re}(c_L)^{TY}$	10^{-22}	10^{-17}	10^{-27}	$\text{Im}(c_L)^{TY}$	10^{-22}	10^{-17}	10^{-22}
	$\text{Re}(c_L)^{TZ}$	10^{-20}	10^{-16}	-	$\text{Im}(c_L)^{TZ}$	-	10^{-16}	-

Isotropic	Coefficient	Sensitivity	Coefficient	Sensitivity
	$\tilde{a}^{(3)}$	10^{-7} GeV	$\tilde{a}_{\text{qu}}^{(2)}$	10^{-20} GeV
	$\tilde{c}^{(4)}$	10^{-9}	$\tilde{c}_{\text{qu}}^{(4)}$	10^{-10}
	$\tilde{c}^{(5)}$	10^{-18} GeV ⁻¹	$\tilde{c}_{\text{qu}}^{(5)}$	10^{-19} GeV ⁻¹
	$\tilde{c}^{(6)}$	10^{-9} GeV ⁻²	$\tilde{c}_{\text{qu}}^{(6)}$	10^{-10} GeV ⁻²
	$\tilde{c}^{(7)}$	10^{-29} GeV ⁻³	$\tilde{c}_{\text{qu}}^{(7)}$	10^{-19} GeV ⁻³
	$\tilde{c}^{(8)}$	10^{-11} GeV ⁻⁴	$\tilde{c}_{\text{qu}}^{(8)}$	10^{-18} GeV ⁻⁴
	$\tilde{c}^{(9)}$	10^{-40} GeV ⁻⁵	$\tilde{c}_{\text{qu}}^{(9)}$	10^{-18} GeV ⁻⁵
	$\tilde{c}^{(10)}$	10^{-14} GeV ⁻⁶	$\tilde{c}_{\text{qu}}^{(10)}$	10^{-18} GeV ⁻⁶

Table D6. Electron sector, $d = 3, 4$ (part 1 of 3)

Combination	Result	System	Ref.
$ b_0 $	$< 2 \times 10^{-14}$ GeV	Cs spectroscopy	[30]*, [31]*
"	$< 2 \times 10^{-12}$ GeV	Tl spectroscopy	[30]*, [31]*
"	$< 7 \times 10^{-15}$ GeV	Dy spectroscopy	[30]*, [31]*

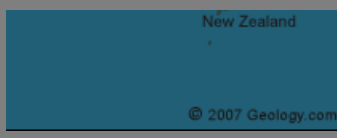
Table D6. Electron sector, $d = 3, 4$ (part 2 of 3)

Combination	Result	System	Ref.
$\tilde{a}^{\text{UR}(4)}$	$< 1.5 \times 10^{-15}$	Astrophysics	[41]*, [18]*
"	$> -5 \times 10^{-13}$	"	[42]*, [18]*
$\frac{1}{2}(\tilde{b}_T + \tilde{d}_- - 2\tilde{g}_c - 3\tilde{g}_T + \dots)$	$(-1.3 \text{ to } 0.2) \times 10^{-15}$	"	[43]*, [18]*
$\frac{1}{2}(2\tilde{g}_c - \tilde{g}_T - \tilde{b}_T + 4\tilde{d}_+ - \dots)$	$> -1.2 \times 10^{-16}$	"	[44]*, [18]*

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

...but nobody found Lorentz violation (so far)

$-7 \text{ to } 4) \times 10^{-15}$	"	[58]*	$\times 10^{-9}$	"	[49]
$i \text{ to } 1.5) \times 10^{-15}$	"	[58]*	$\times 10^{-9}$	"	[49]
$-4 \text{ to } 2) \times 10^{-17}$	"	[58]*	$\times 10^{-6}$	Nuclear binding energy	[50]
$< 1.3 \times 10^{-15}$	"	[59]*	$\times 10^{-6}$	Cs interferometer	[51]
	"		$\times 10^{-15}$	Collider physics	[52]*
$< 2.5 \times 10^{-15}$	"	[59]*	$\times 10^{-14}$	"	[52]*
	"		$\times 10^{-15}$	"	[52]*
	"		$\times 10^{-13}$	"	[52]*
	"		$\times 10^{-11}$	1S-2S transition	[53]*
$.8) \times 10^{-27}$ GeV	Torsion pendulum	[32]	$\times 10^{-16}$	Optical, microwave resonators	[54]*
$.4) \times 10^{-27}$ GeV	"	[32]	$\times 10^{-16}$	"	[54]*
$.9) \times 10^{-27}$ GeV	"	[32]	$\times 10^{-16}$	"	[54]*
$.2) \times 10^{-27}$ GeV	"	[32]	$\times 10^{-16}$	"	[54]*
$< 2 \times 10^{-14}$	Astrophysics	[60]*	$\times 10^{-16}$	"	[54]*
$< 3 \times 10^{-15}$	"	[60]*	$\times 10^{-16}$	"	[54]*
$< 2 \times 10^{-15}$	"	[60]*	$\times 10^{-16}$	"	[54]*
$< 2 \times 10^{-14}$	"	[60]*	$\times 10^{-16}$	"	[54]*
$< 7 \times 10^{-15}$	"	[60]*	$\times 10^{-16}$	"	[54]*
$< 5 \times 10^{-14}$	"	[60]*	$\times 10^{-16}$	"	[54]*
$< 5 \times 10^{-15}$	"	[60]*	$\times 10^{-16}$	"	[54]*
$< 8 \times 10^{-17}$	"	[60]*	$\times 10^{-16}$	"	[54]*
$< 10^{-22}$ GeV	Hg/Cs comparison	[39], [40]*			
$< 10^{-19}$ GeV	Astrophysics	[28]*			
$< 10^{-17}$ GeV	Astrophysics	[28]*			
$< 10^{-17}$ GeV	"	[28]*			
$< 10^{-18}$ GeV	"	[28]*			
$< 10^{-22}$ GeV	Penning trap	[28]*			
$< 10^{-22}$ GeV	Hg/Cs comparison	[39], [40]*			



So far no experiments find Lorentz violation...

most precise something

“Extraordinary discovery requires extraordinary evidence”
 - Carl Sagan



There are too many Lorentz violation experiments to summarize in the summary documents!

...but nobody

Table S3. Maximal sensitivities for the photon sector

Table S2.

Coefficient

\tilde{b}_X
\tilde{b}_Y
\tilde{b}_Z
\tilde{b}_T
$\tilde{b}_J, (J = X, Y, Z)$

\tilde{c}_-	10^{-20} GeV	10^{-24}
\tilde{c}_Q	10^{-17} GeV	10^{-21}
\tilde{c}_X	10^{-21} GeV	10^{-25}
\tilde{c}_Y	10^{-21} GeV	10^{-25}
\tilde{c}_Z	10^{-20} GeV	10^{-24}
\tilde{c}_{TX}	10^{-18} GeV	10^{-20}
\tilde{c}_{TY}	10^{-18} GeV	10^{-20}
\tilde{c}_{TZ}	10^{-20} GeV	10^{-20}
\tilde{c}_{TT}	10^{-18} GeV	10^{-11}

Table S4. Maximal sensitivities for the neutrino

d = 3	Coefficient	Sensitivity			Coefficient
		$\epsilon\mu$	$\epsilon\tau$	$\mu\tau$	
	$\text{Re}(a_L)^T$	10^{-20} GeV	10^{-19} GeV	-	$\text{Im}(a_L)$
	$\text{Re}(a_L)^X$	10^{-20} GeV	10^{-19} GeV	10^{-23} GeV	$\text{Im}(a_L)$
	$\text{Re}(a_L)^Y$	10^{-21} GeV	10^{-19} GeV	10^{-23} GeV	$\text{Im}(a_L)$
	$\text{Re}(a_L)^Z$	10^{-19} GeV	10^{-19} GeV	-	$\text{Im}(a_L)$

d = 4	Coefficient	Sensitivity			Coefficient	$\epsilon\mu$	$\epsilon\tau$	$\mu\tau$
		$\epsilon\mu$	$\epsilon\tau$	$\mu\tau$				
	$\text{Re}(c_L)^{XY}$	10^{-21}	10^{-17}	10^{-23}	$\text{Im}(c_L)^{XY}$	10^{-21}	10^{-17}	10^{-21}
	$\text{Re}(c_L)^{XZ}$	10^{-21}	10^{-17}	10^{-23}	$\text{Im}(c_L)^{XZ}$	10^{-21}	10^{-17}	10^{-21}
	$\text{Re}(c_L)^{YZ}$	10^{-21}	10^{-16}	10^{-23}	$\text{Im}(c_L)^{YZ}$	10^{-21}	10^{-16}	10^{-21}
	$\text{Re}(c_L)^{XX}$	10^{-21}	10^{-16}	10^{-23}	$\text{Im}(c_L)^{XX}$	10^{-21}	10^{-16}	10^{-21}
	$\text{Re}(c_L)^{YY}$	10^{-21}	10^{-16}	10^{-23}	$\text{Im}(c_L)^{YY}$	10^{-21}	10^{-16}	10^{-21}
	$\text{Re}(c_L)^{ZZ}$	10^{-19}	10^{-16}	-	$\text{Im}(c_L)^{ZZ}$	-	10^{-16}	-
	$\text{Re}(c_L)^{TT}$	10^{-19}	10^{-17}	-	$\text{Im}(c_L)^{TT}$	-	10^{-17}	-
	$\text{Re}(c_L)^{TX}$	10^{-22}	10^{-17}	10^{-27}	$\text{Im}(c_L)^{TX}$	10^{-22}	10^{-17}	10^{-22}
	$\text{Re}(c_L)^{TY}$	10^{-22}	10^{-17}	10^{-27}	$\text{Im}(c_L)^{TY}$	10^{-22}	10^{-17}	10^{-22}
	$\text{Re}(c_L)^{TZ}$	10^{-20}	10^{-16}	-	$\text{Im}(c_L)^{TZ}$	-	10^{-16}	-

Isotropic	Coefficient	Sensitivity	Coefficient	Sensitivity
	$\tilde{a}^{(3)}$	10^{-7} GeV	$\tilde{a}_{\text{qu}}^{(2)}$	10^{-20} GeV
	$\tilde{c}^{(4)}$	10^{-9}	$\tilde{c}_{\text{qu}}^{(4)}$	10^{-10}
	$\tilde{a}^{(5)}$	10^{-18} GeV ⁻¹	$\tilde{a}_{\text{qu}}^{(5)}$	10^{-19} GeV ⁻¹
	$\tilde{c}^{(6)}$	10^{-9} GeV ⁻²	$\tilde{c}_{\text{qu}}^{(6)}$	10^{-10} GeV ⁻²
	$\tilde{a}^{(7)}$	10^{-29} GeV ⁻³	$\tilde{a}_{\text{qu}}^{(7)}$	10^{-19} GeV ⁻³
	$\tilde{c}^{(8)}$	10^{-11} GeV ⁻⁴	$\tilde{c}_{\text{qu}}^{(8)}$	10^{-18} GeV ⁻⁴
	$\tilde{a}^{(9)}$	10^{-40} GeV ⁻⁵	$\tilde{a}_{\text{qu}}^{(9)}$	10^{-18} GeV ⁻⁵
	$\tilde{c}^{(10)}$	10^{-14} GeV ⁻⁶	$\tilde{c}_{\text{qu}}^{(10)}$	10^{-18} GeV ⁻⁶

Table D6. Electron sector, d = 3, 4 (part 1 of 3)

Combination Result System Ref.

$8) \times 10^{-27}$ GeV	Torsion pendulum	[32]	$\times 10^{-13}$	=	[54]*
$.4) \times 10^{-27}$ GeV	=	[32]	$\times 10^{-16}$	=	[54]*
$.9) \times 10^{-27}$ GeV	=	[32]	$\times 10^{-16}$	=	[54]*
$.2) \times 10^{-27}$ GeV	=	[32]	$\times 10^{-16}$	=	[54]*
$< 2 \times 10^{-14}$	Astrophysics	[60]*	$\times 10^{-16}$	=	[54]*
$< 3 \times 10^{-15}$	=	[60]*	$\times 10^{-16}$	=	[54]*
$< 2 \times 10^{-15}$	=	[60]*	$\times 10^{-16}$	=	[54]*
$< 2 \times 10^{-14}$	=	[60]*	$\times 10^{-16}$	=	[54]*
$< 7 \times 10^{-15}$	=	[60]*	$\times 10^{-16}$	=	[54]*
$< 5 \times 10^{-14}$	=	[60]*	$\times 10^{-16}$	=	[54]*
$< 5 \times 10^{-15}$	=	[60]*	$\times 10^{-16}$	=	[54]*
$< 8 \times 10^{-17}$	=	[60]*	$\times 10^{-16}$	=	[54]*
$< 10^{-22}$ GeV	Hg/Cs comparison	[39], [40]*	$\times 10^{-16}$	=	[54]*
$< 10^{-19}$ GeV	Astrophysics	[28]*	$\times 10^{-16}$	=	[54]*
$< 10^{-17}$ GeV	Astrophysics	[28]*	$\times 10^{-16}$	=	[54]*
$< 10^{-17}$ GeV	=	[28]*	$\times 10^{-16}$	=	[54]*
$< 10^{-18}$ GeV	=	[28]*	$\times 10^{-16}$	=	[54]*
$< 10^{-22}$ GeV	Penning trap	[28]*	$\times 10^{-16}$	=	[54]*
$< 10^{-22}$ GeV	Hg/Cs comparison	[39], [40]*	$\times 10^{-16}$	=	[54]*

New Zealand

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So far no experiments find Lorentz violation...

most precise something

“Extraordinary discovery requires extraordinary evidence”

- Carl Sagan



“Extraordinary discovery requires extraordinary particles”

- Teppei



Neutrino!

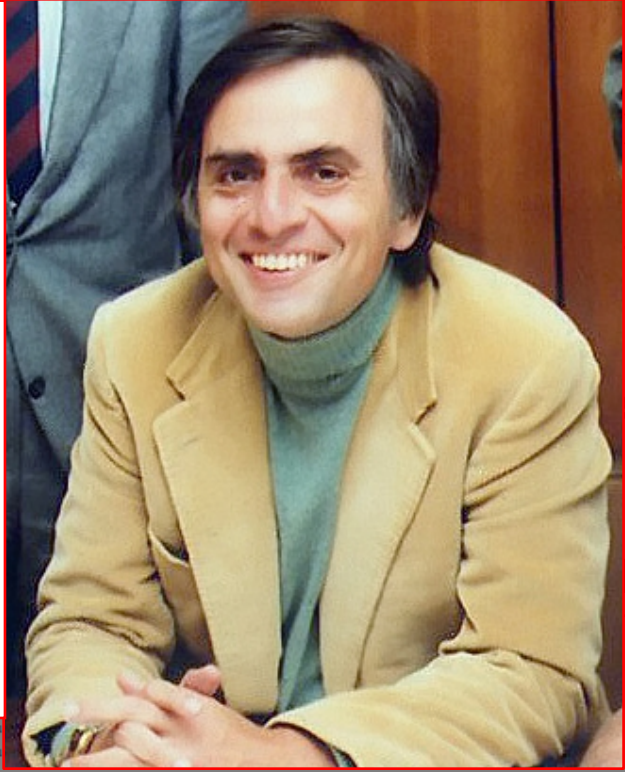
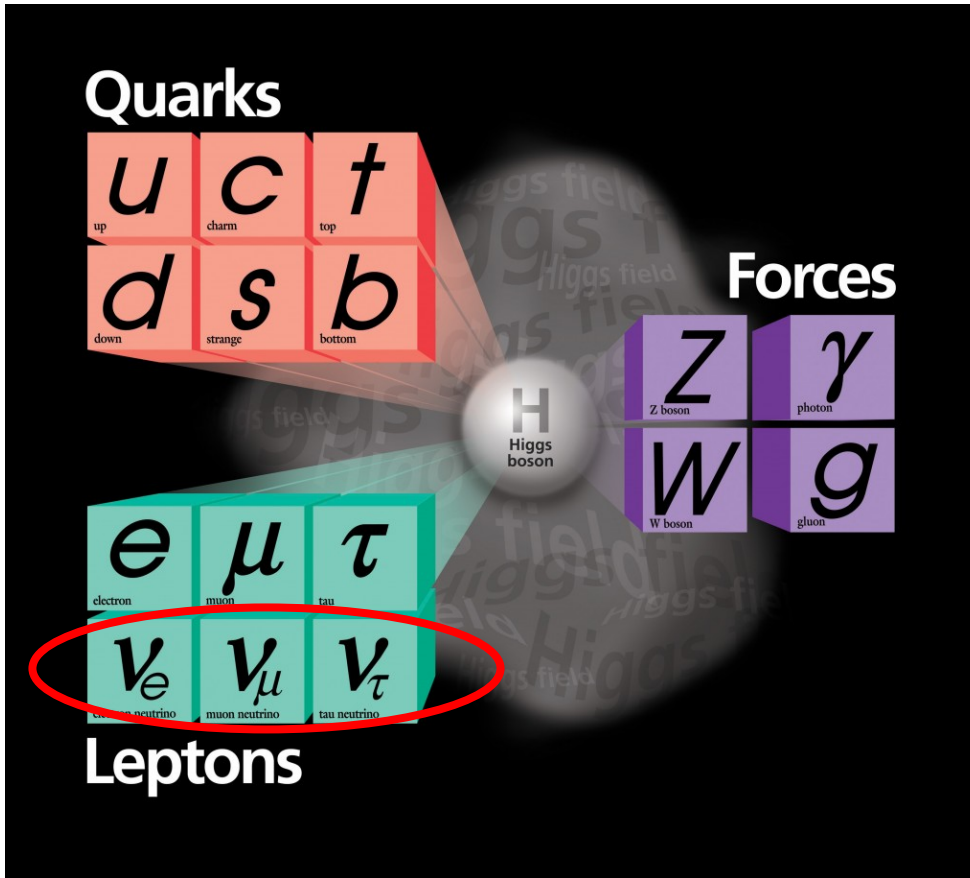


Table S2. Coefficient		Table S3. Maximal sensitivities for the photon sector					Table D6. Electron sector, $d=3,4$ (part 1 of 3)						
		Isotropic		Coefficient			Sensitivity		Coefficient		Sensitivity		
\tilde{b}_X	10^{-19} GeV			$\text{Re}(c_L)^{YZ}$	10^{-21}	10^{-16}	10^{-23}	$\text{Im}(c_L)^{YZ}$	10^{-21}	10^{-16}	10^{-21}	10^{-16}	
\tilde{b}_Y	10^{-19} GeV			$\text{Re}(c_L)^{XX}$	10^{-21}	10^{-16}	10^{-23}	$\text{Im}(c_L)^{XX}$	10^{-21}	10^{-16}	10^{-21}	10^{-16}	
\tilde{b}_Z	10^{-19} GeV			$\text{Re}(c_L)^{YY}$	10^{-21}	10^{-16}	10^{-23}	$\text{Im}(c_L)^{YY}$	10^{-21}	10^{-16}	10^{-21}	10^{-16}	
\tilde{b}_T	10^{-19} GeV			$\text{Re}(c_L)^{ZZ}$	10^{-19}	10^{-16}		$\text{Im}(c_L)^{ZZ}$		10^{-16}			
$\tilde{b}_J, (J=X,Y,Z)$	10^{-19} GeV			$\text{Re}(c_L)^{JT}$	10^{-19}	10^{-17}		$\text{Im}(c_L)^{JT}$		10^{-17}			
\tilde{c}_-	10^{-26} GeV			$\text{Re}(c_L)^{TY}$	10^{-22}	10^{-17}	10^{-27}	$\text{Im}(c_L)^{TY}$	10^{-22}	10^{-17}	10^{-22}	10^{-17}	
\tilde{c}_Q	10^{-26} GeV			$\text{Re}(c_L)^{TY}$	10^{-22}	10^{-17}	10^{-27}	$\text{Im}(c_L)^{TY}$	10^{-22}	10^{-17}	10^{-22}	10^{-17}	
\tilde{c}_X	10^{-26} GeV			$\text{Re}(c_L)^{TZ}$	10^{-20}	10^{-16}		$\text{Im}(c_L)^{TZ}$		10^{-16}			
\tilde{c}_Y	10^{-26} GeV												
\tilde{c}_Z	10^{-26} GeV												
\tilde{c}_T	10^{-27} GeV	10^{-7} GeV											
\tilde{c}_{c_1}	10^{-26} GeV												
\tilde{c}_Q													
\tilde{c}_-													
$\tilde{g}_{TJ}, (J=X,Y,Z)$	10^{-17} GeV												
\tilde{g}_{XY}	10^{-17} GeV												
\tilde{g}_{YX}	10^{-17} GeV												
\tilde{g}_{ZX}	10^{-18} GeV												
\tilde{g}_{XZ}	10^{-17} GeV												
\tilde{g}_{YZ}	10^{-17} GeV												
\tilde{g}_{ZY}	10^{-18} GeV												
\tilde{g}_{DX}	10^{-22} GeV	10^{-27} GeV											
\tilde{g}_{DY}	10^{-22} GeV	10^{-27} GeV	10^{-28} GeV										
\tilde{g}_{DZ}	10^{-22} GeV												

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



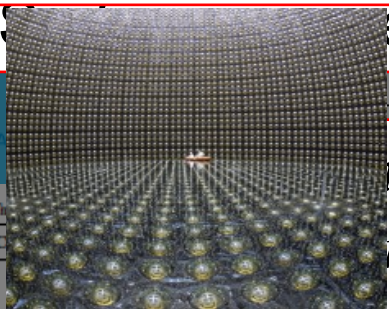
Neutrinos

- 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)



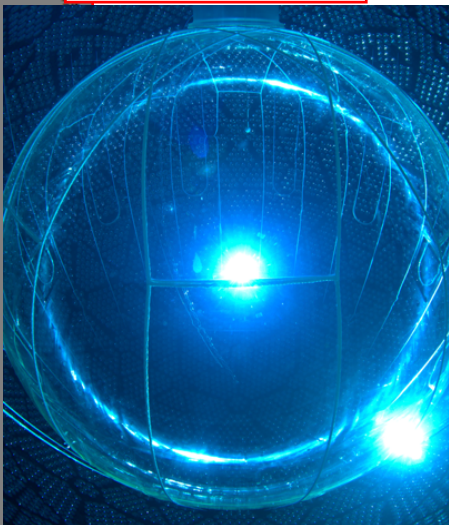
PLB718(2013)1303

Daya Bay (China)



PRD98(2018)092013

SNO (Canada)



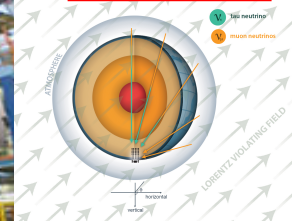
PRD98(2018)112013

MINOS FD (USA)



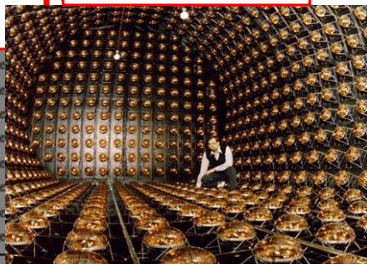
PRL105(2010)151601

IceCube-86



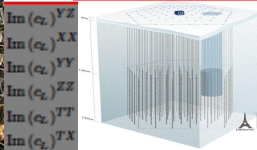
Nature Physics 14(2018)961

LSND (USA)



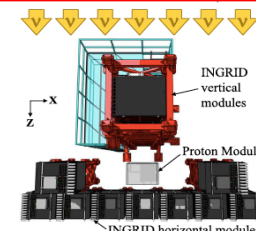
PRD72(2005)076004

IceCube-40



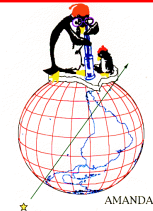
PRD82(2010)112003

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?

Search

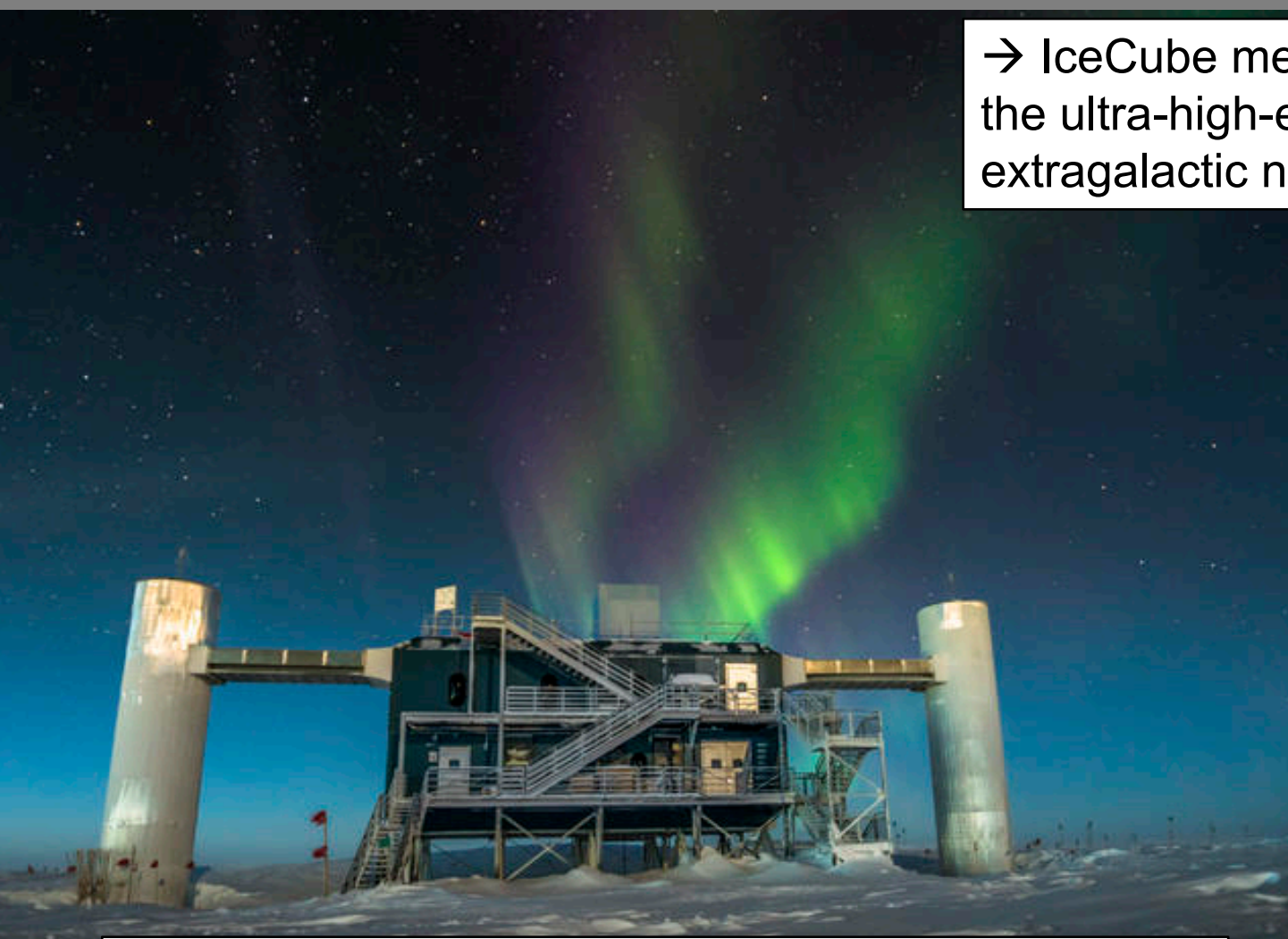
ARCTIC OCEAN

Table S2. Maximal

Coefficient

\bar{b}_X	10
\bar{b}_Y	10
\bar{b}_Z	10
\bar{b}_T	10
$\bar{b}_J, (J = X, Y, Z)$	10
\bar{c}_-	10
\bar{c}_Q	10
\bar{c}_X	10
\bar{c}_Y	10
\bar{c}_Z	10
\bar{c}_{TX}	10
\bar{c}_{TY}	10
\bar{c}_{TZ}	10
\bar{c}_{TT}	10
\bar{d}_+	10
\bar{d}_-	10
\bar{d}_Q	10
\bar{d}_{XY}	10
\bar{d}_{YZ}	10
\bar{d}_{ZX}	10
\bar{d}_X	10
\bar{d}_Y	10
\bar{d}_Z	10
\bar{H}_{XT}	10
\bar{H}_{YT}	10
\bar{H}_{ZT}	10

→ IceCube measures the ultra-high-energy extragalactic neutrinos

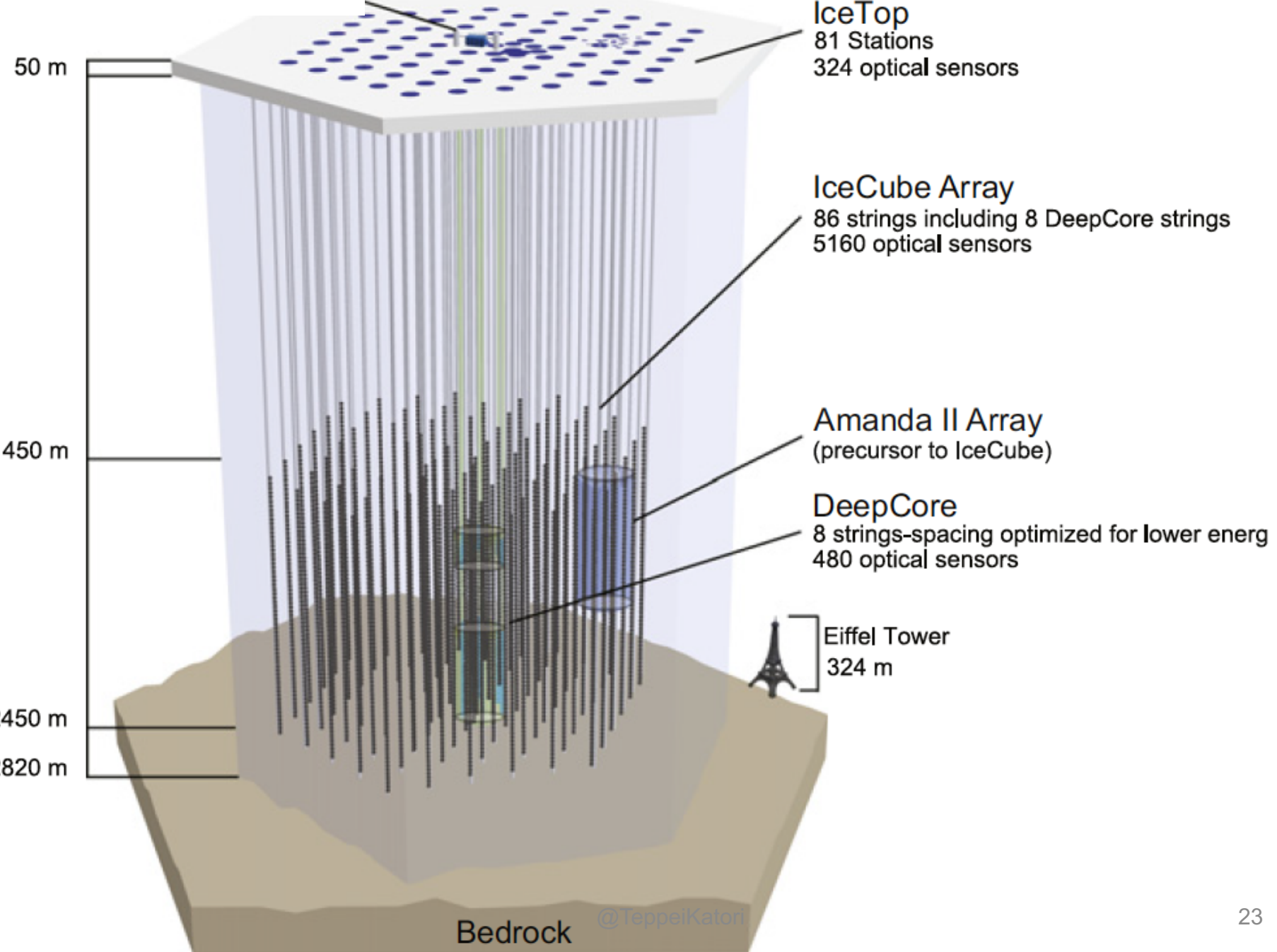


IceCube Neutrino Observatory (Antarctica)

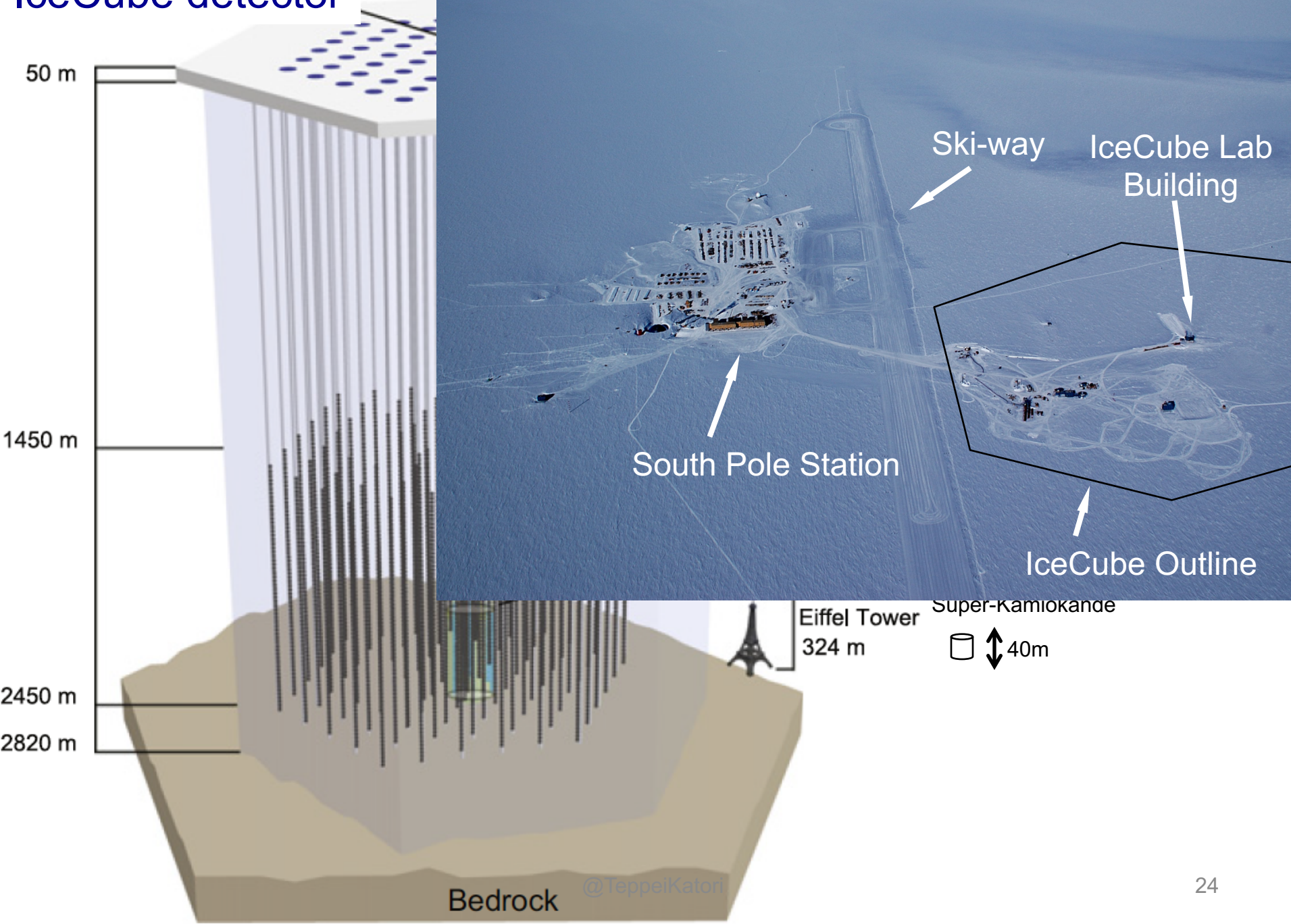
System	Ref.
Astrophysics	[41]*, [18]*
"	[42]*, [18]*
"	[43]*, [18]*
"	[44]*, [18]*
"	[8]*
"	[49]
"	[49]
Nuclear binding energy	[50]
Cs interferometer	[51]
Collider physics	[52]*
"	[52]*
"	[52]*
"	[52]*
1S-2S transition	[53]*
Optical, microwave resonators	[54]*
"	[54]*
"	[54]*
"	[54]*
"	[54]*

“Extraordinary discovery requires *extraordinary particles* with *the extraordinary energy* and *extraordinary propagation distance*”
 - Tepeei

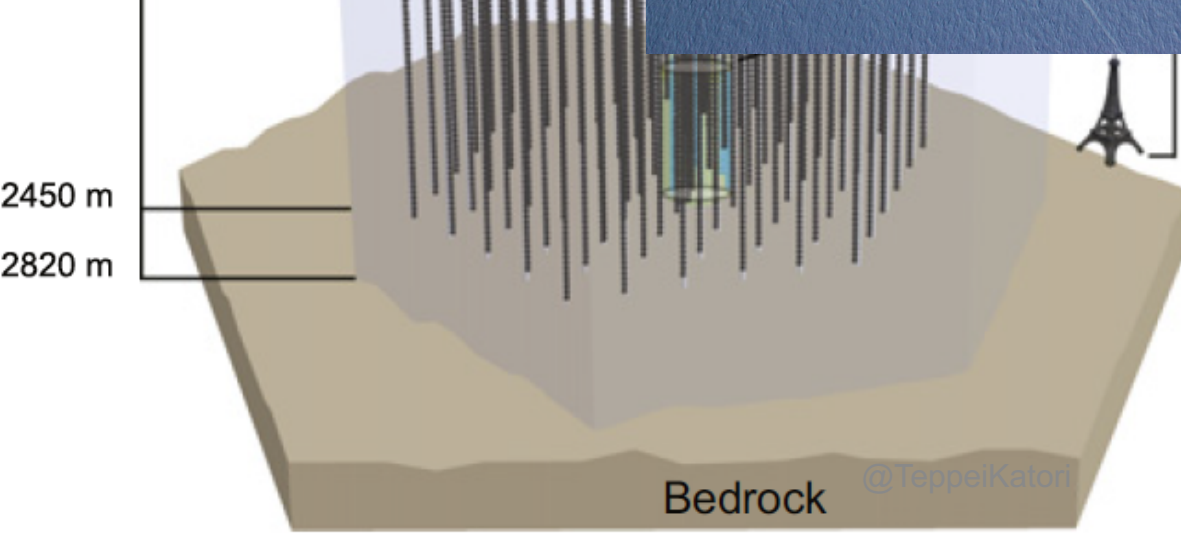
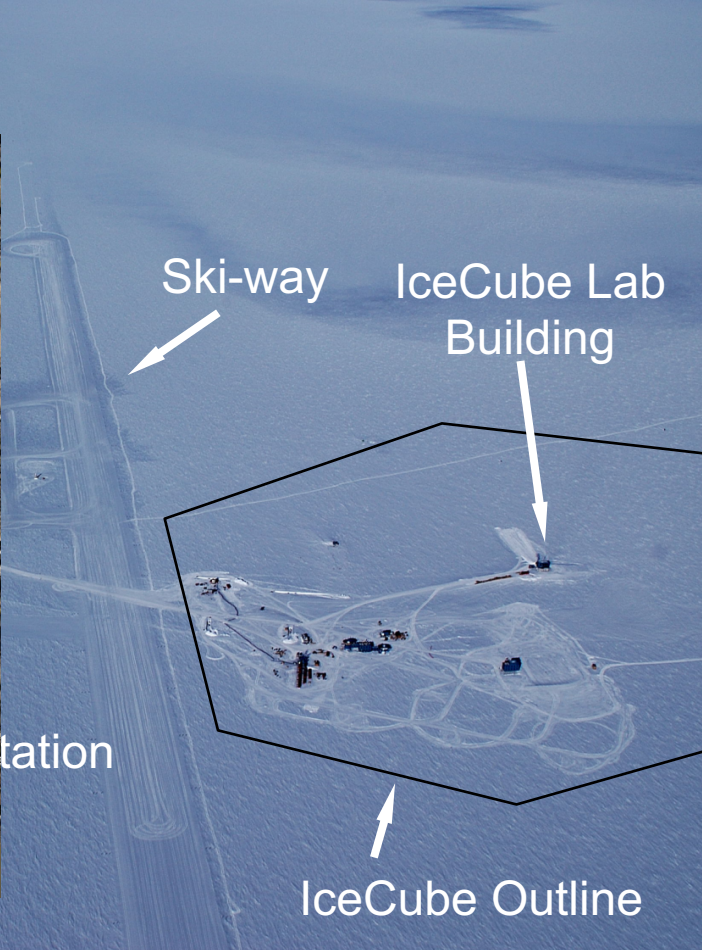
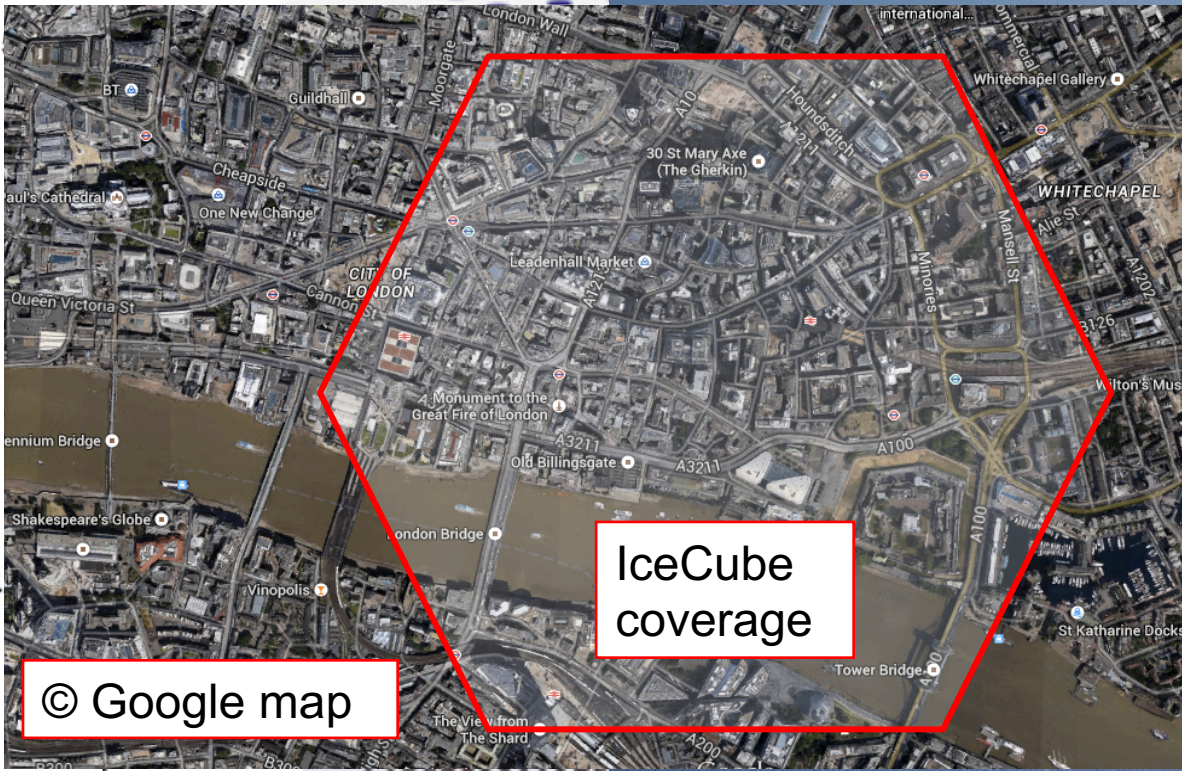
IceCube detector




IceCube detector

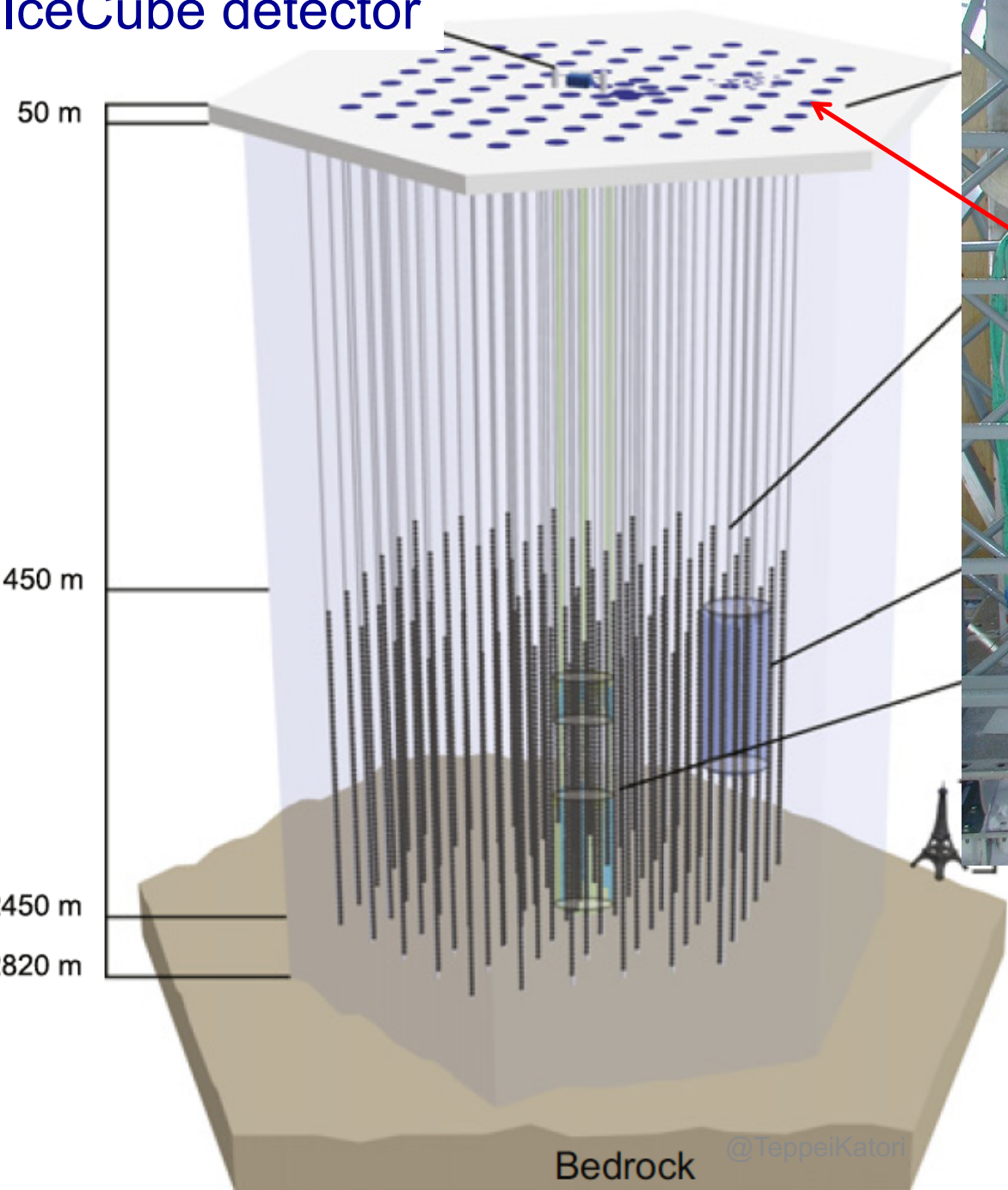


IceCube detector



Super-Kamiokande
 40m

IceCube detector

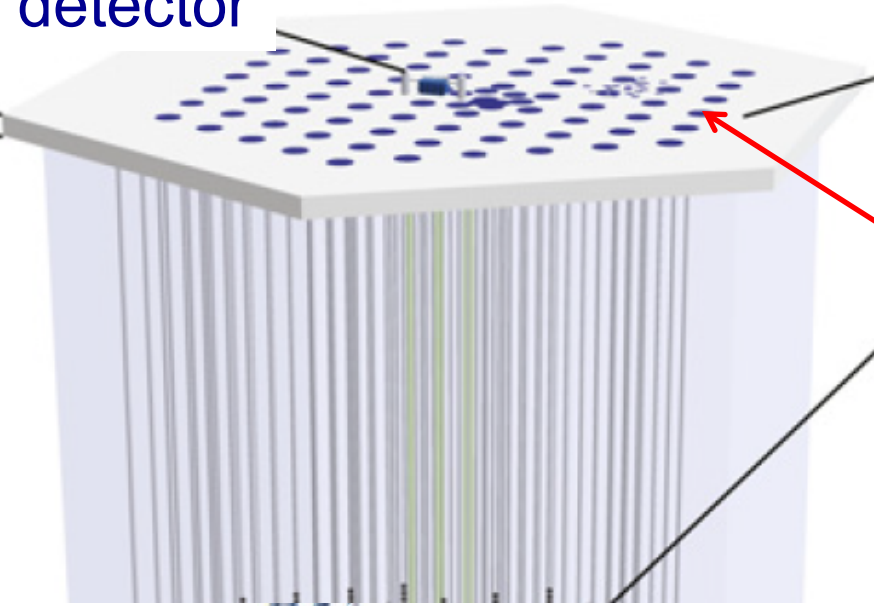


hot water drill

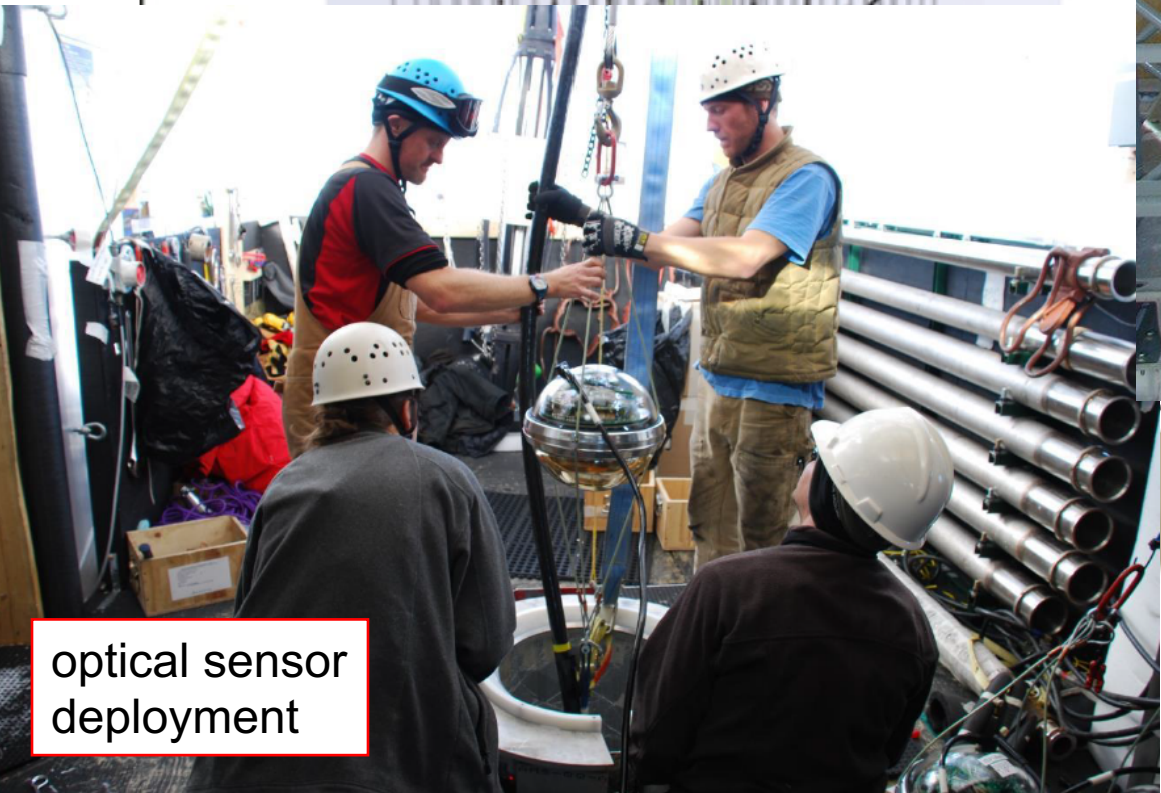


IceCube detector

50 m

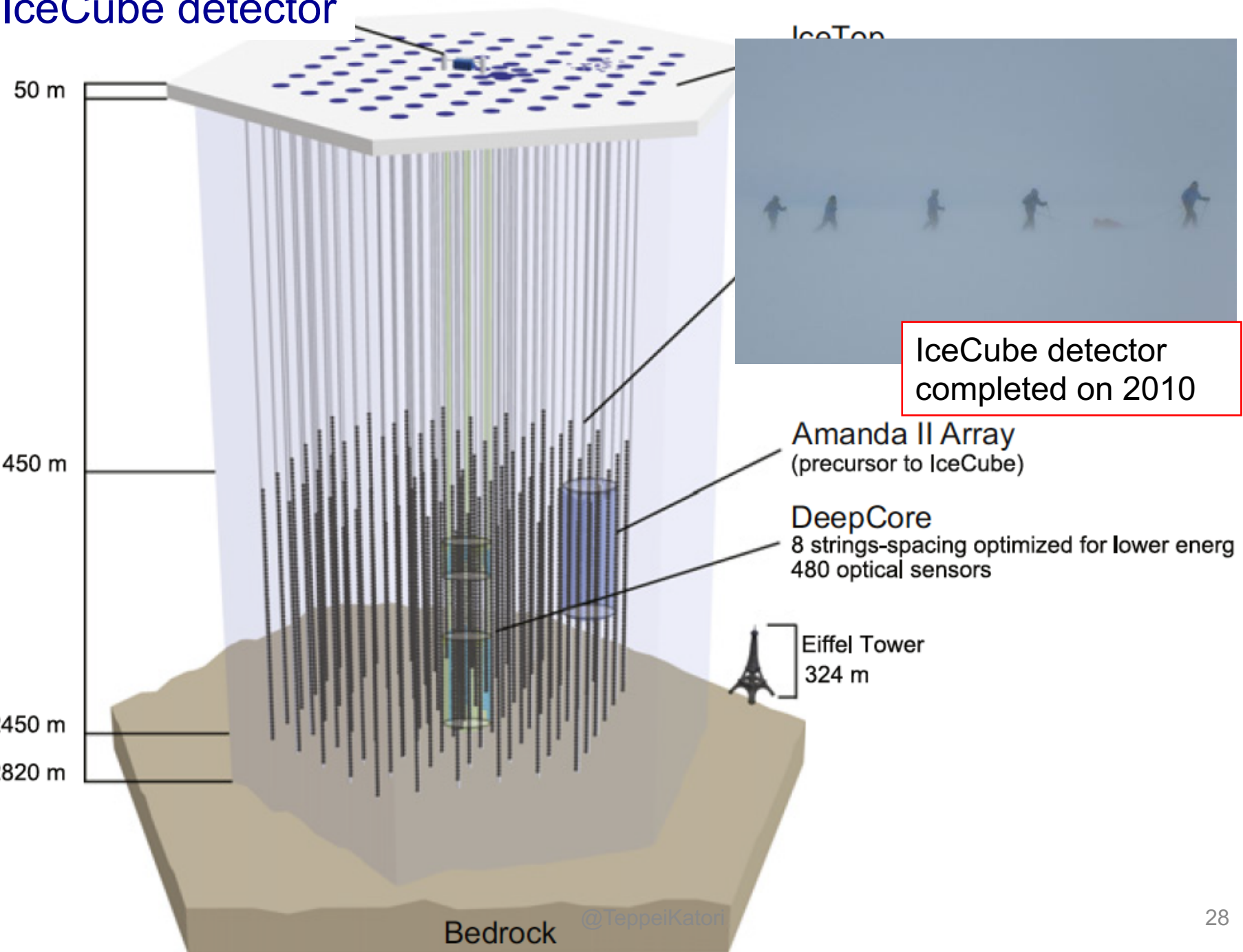


hot water drill



optical sensor deployment

IceCube detector



IceCube detector

50



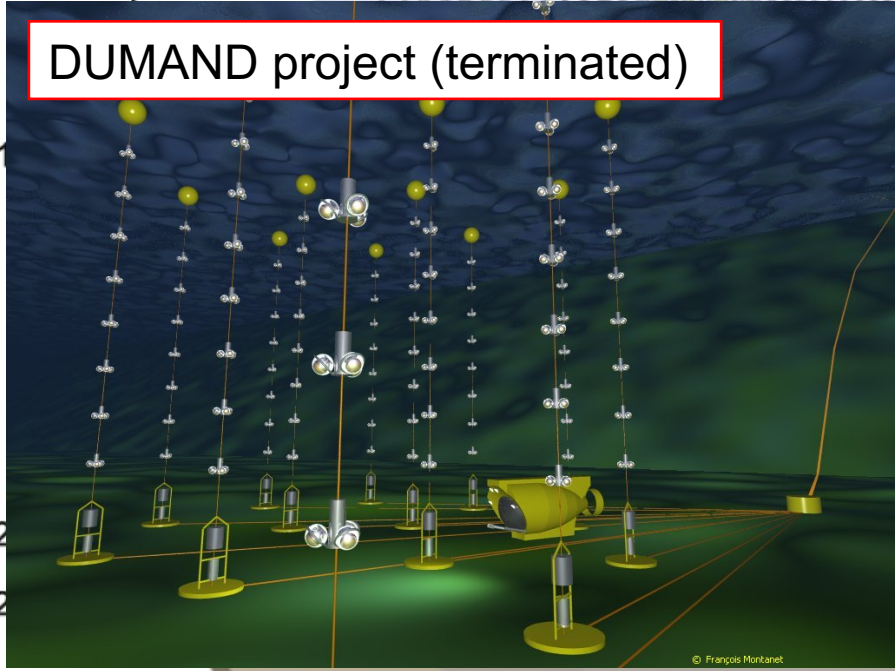
Hawaii

VS.



IceCube detector completed on 2010

DUMAND project (terminated)



Amanda II Array (precursor to IceCube)

DeepCore 8 strings-spacing optimized for lower energy 480 optical sensors

Eiffel Tower 324 m

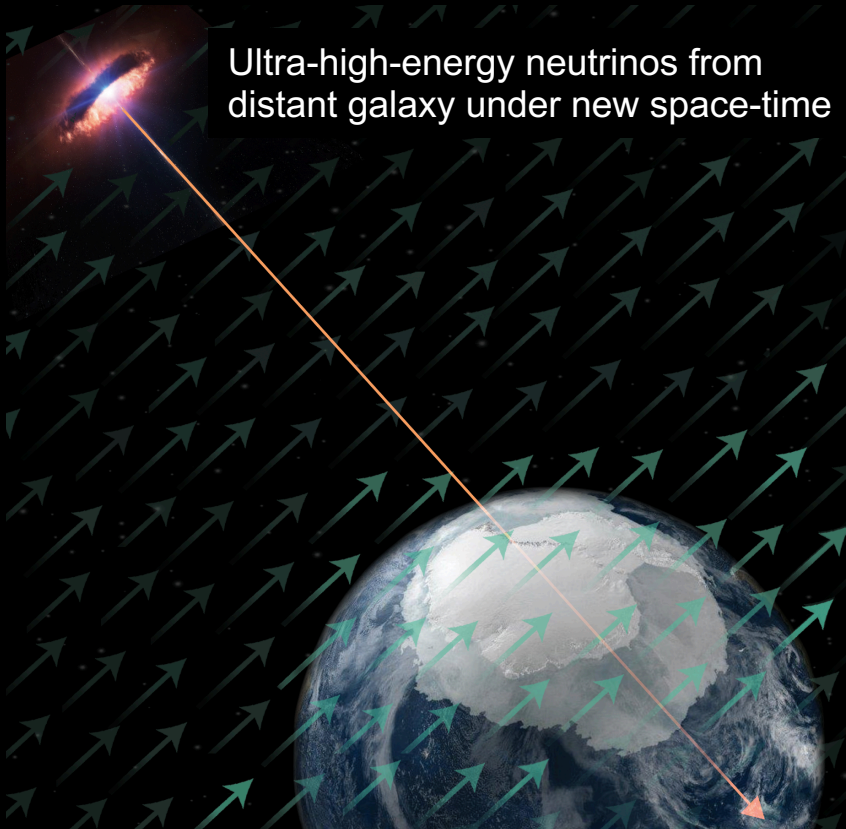
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E(GeV): 6.08e+04
Zen: 44.43 deg
Azi: 357.53 deg
NTrack: 100/446 shown, max E(GeV) == 56675.77
NCasc: 100/444 shown, max E(GeV) == 1.58

Discovery of Ultra-High-Energy Astrophysical Neutrinos

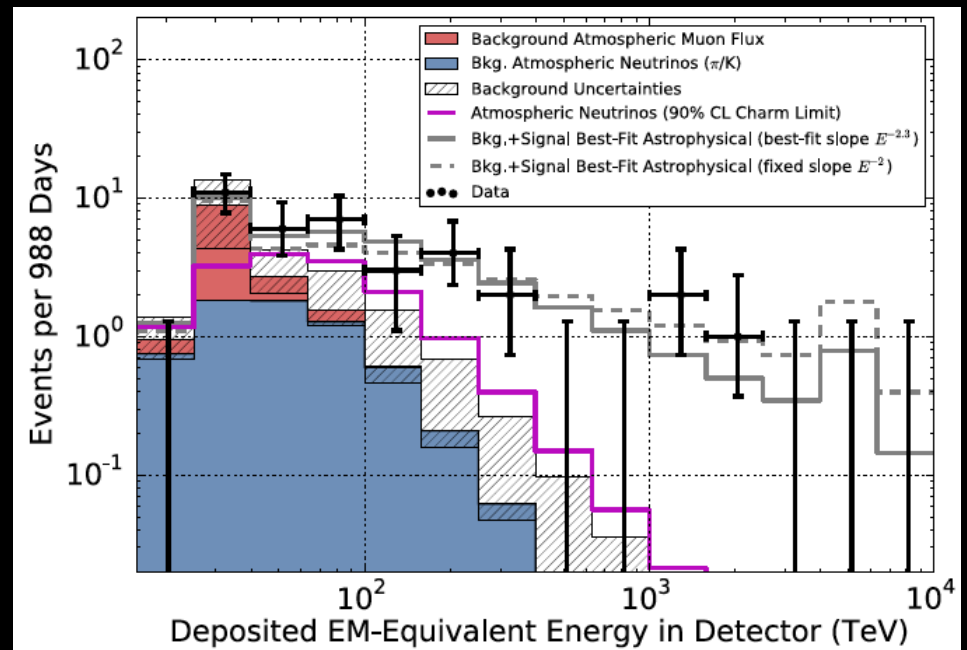
60 TeV to 2000 TeV high energy neutrinos (Large Hadron Collider ~ 7 TeV)

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

Ultra-high-energy neutrinos from distant galaxy under new space-time



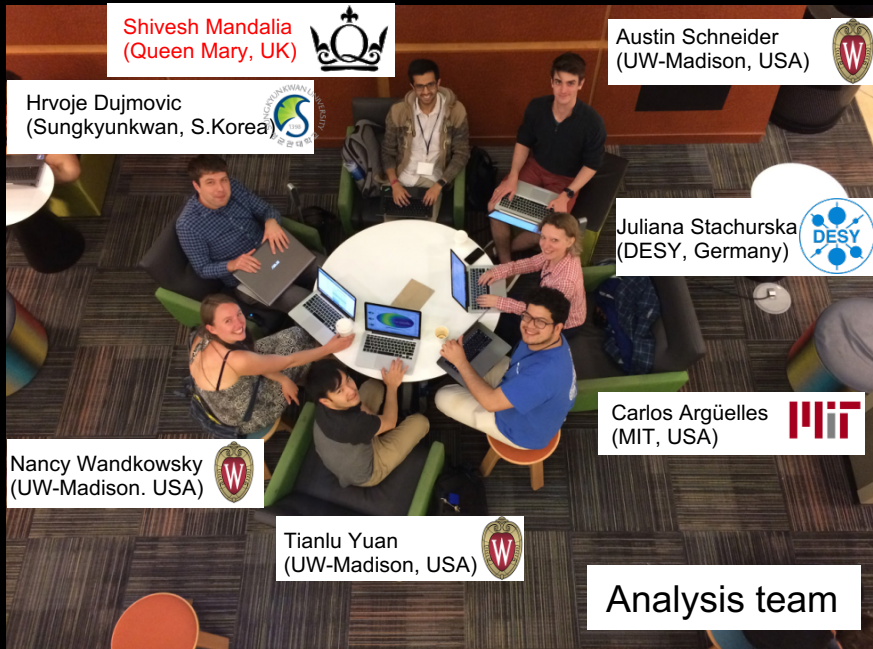
Measured high energy neutrino spectrum



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 (not by me)



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

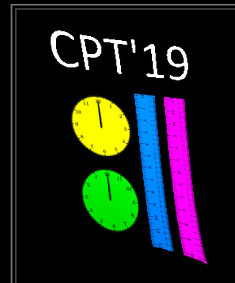
Discovery of Ultra-High-Energy Astrophysical Neutrinos

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 (not by me)

Unfortunately, we didn't discover Lorentz violation..., result was presented at the Lorentz violation conference (last week).

Why no Lorentz violation???



MEETING LINKS

Meeting Home
Registration
Program
Proceedings
Travel
Accommodations

LOCAL LINKS

IUCSS
IU Physics
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

Discovery of Ultra-High-Energy Astrophysical Neutrinos

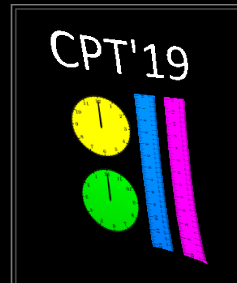
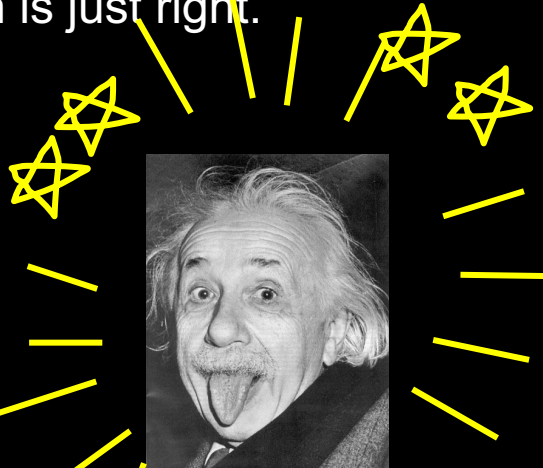
60 TeV to 2000 TeV high energy neutrinos (Large Hadron Collider ~ 7 TeV)

Analysis has been developed to look for Lorentz violation from astrophysical neutrino data (not by me)

Unfortunately, we didn't discover Lorentz violation..., result was presented at the Lorentz violation conference (last week).

Why no Lorentz violation???

1. There is no Lorentz violation.
Einstein is just right.



MEETING LINKS

Meeting Home
Registration
Program
Proceedings
Travel
Accommodations

LOCAL LINKS

IUCSS
IU Physics
IU Astronomy
IU Mathematics
IU Bloomington
Bloomington area

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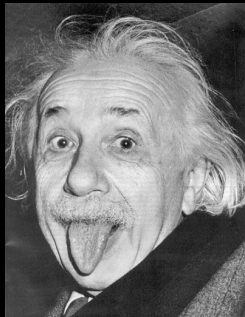
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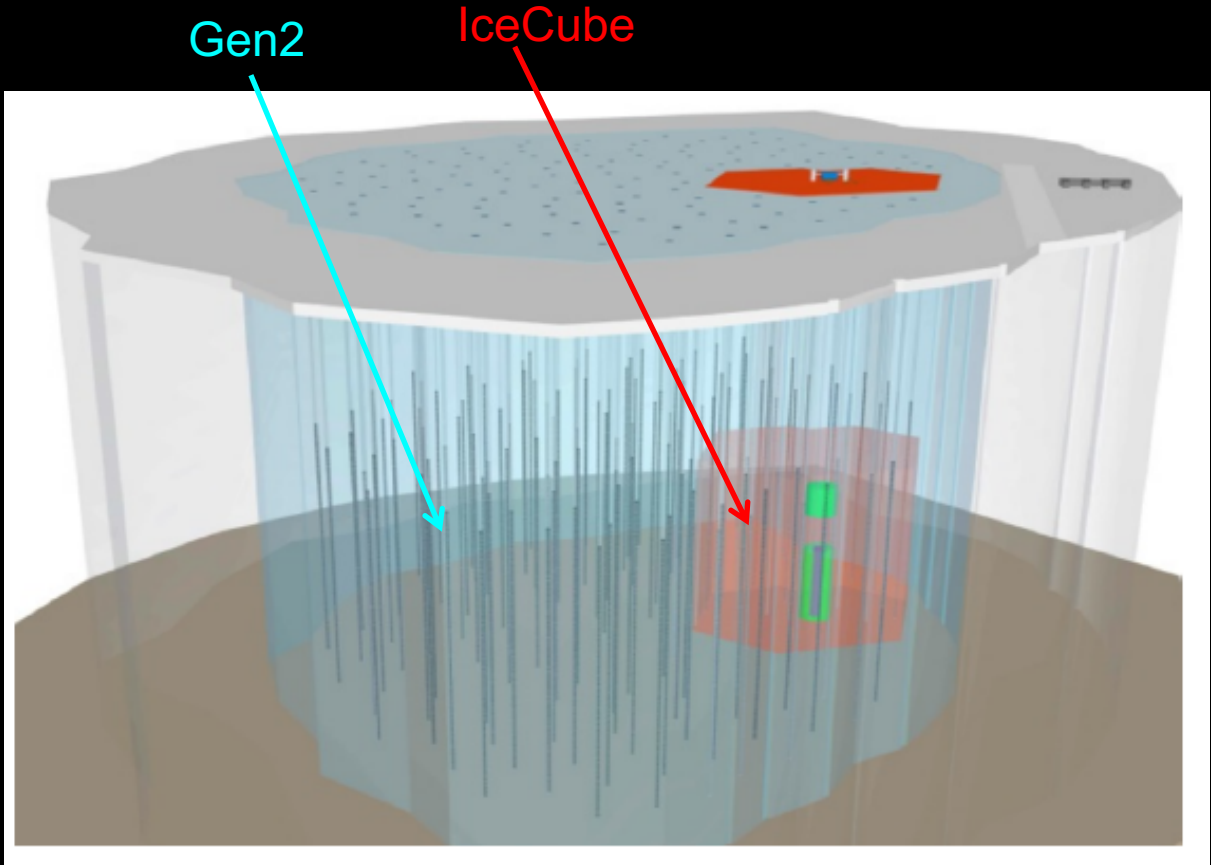
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2. We need a better detector and better simulation, and more advanced analysis!



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)



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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



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...

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Thank you for your attention!

