How Rotation Emerges from the Planck Scale

Effects on Interferometers and Cosmic Acceleration

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https://arxiv.org/abs/1607.03048

http://arxiv.org/abs/1509.07997

The Holometer collaboration

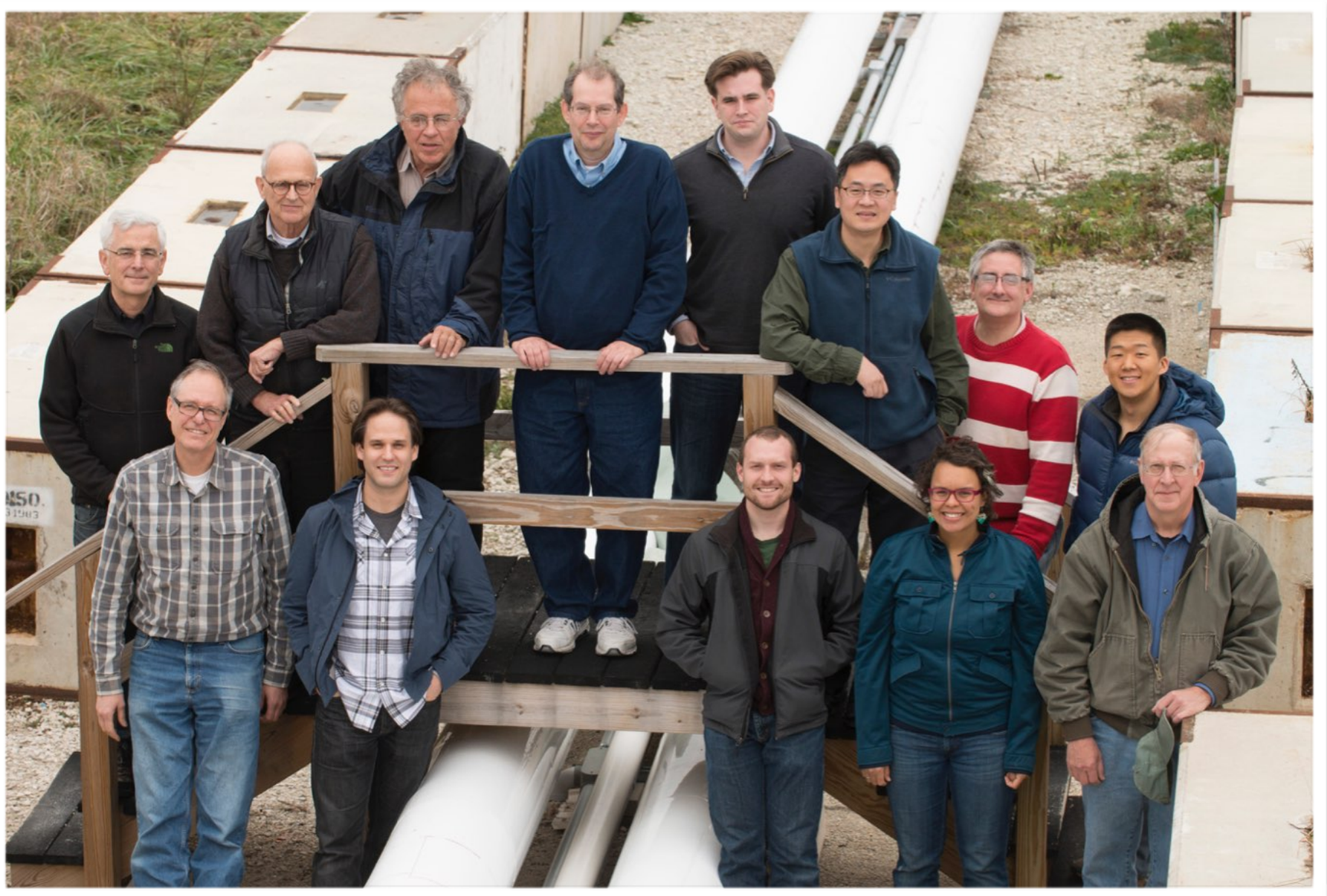
University of Chicago

Fermi National Laboratory

Massachusetts Institute of Technology

Vanderbilt University

University of Michigan



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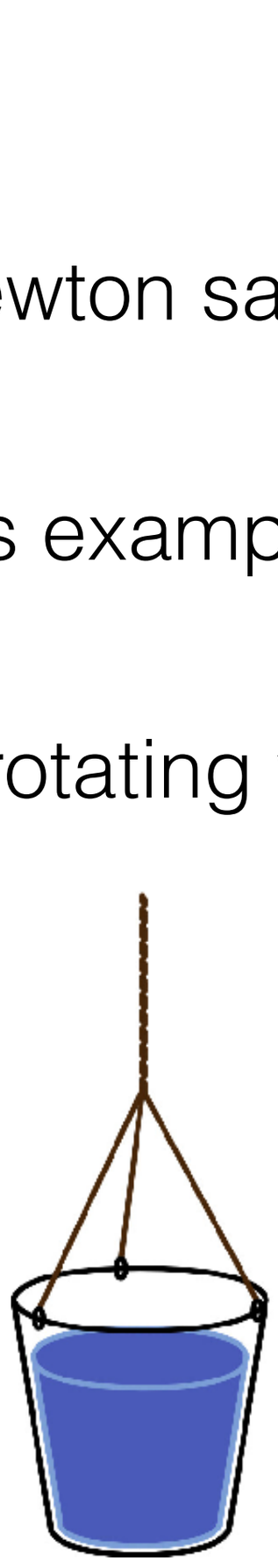
Vanderbilt -> CalTech

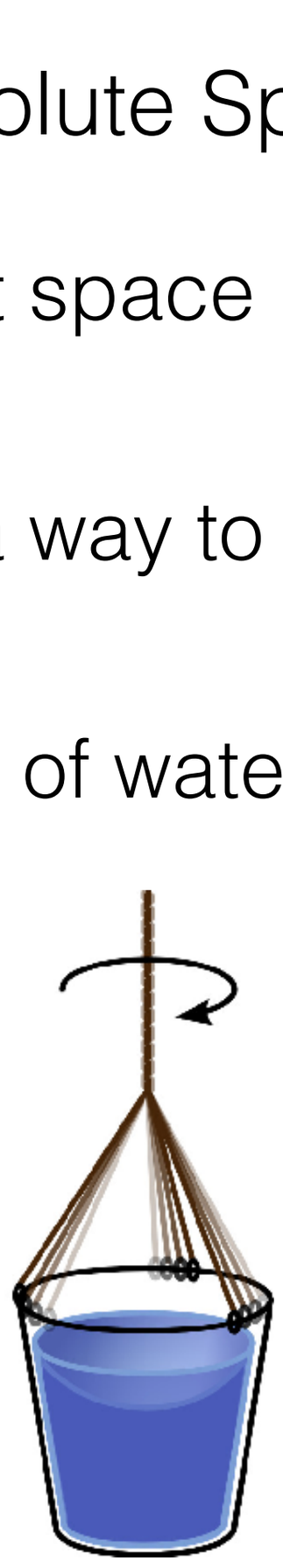
Absolute Space and Rotation

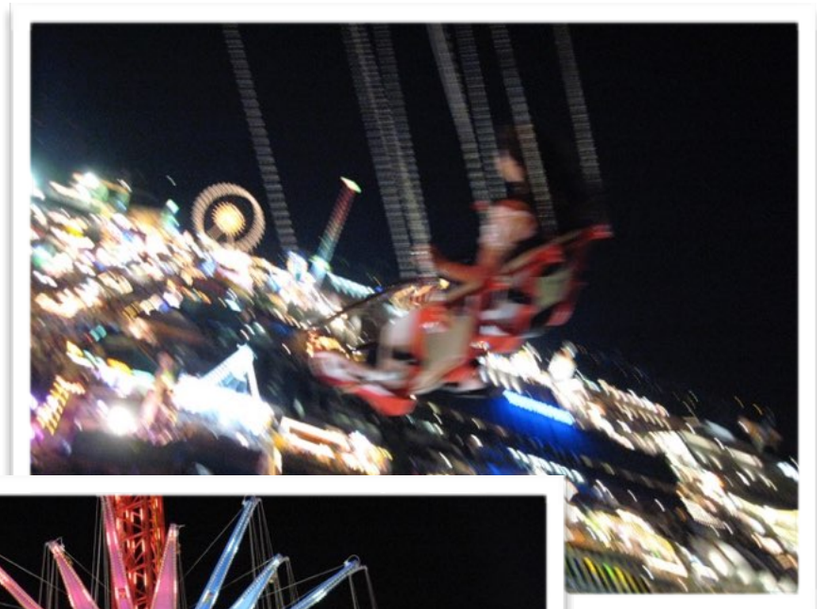
Newton said that space is absolute

His example of a way to measure it:

A rotating vessel of water







Rotation in General Relativity

Space still defines an absolute local inertial frame

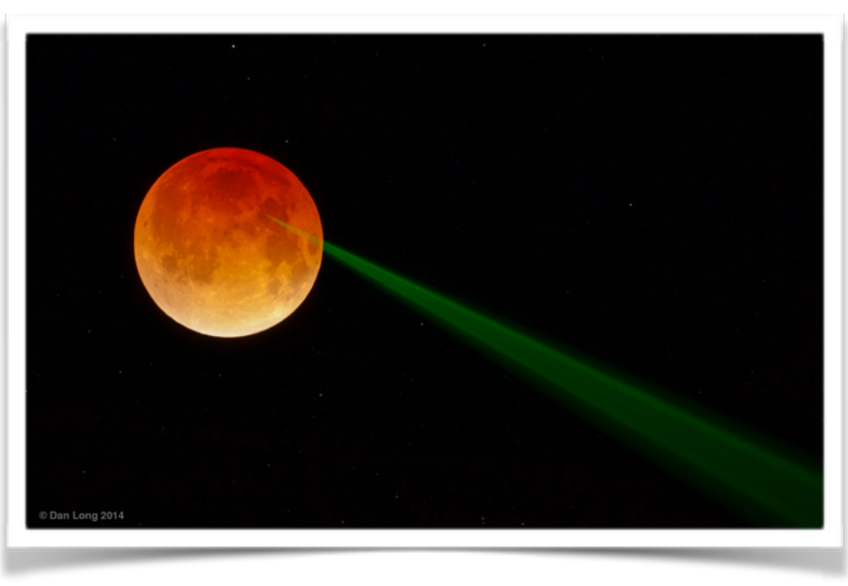
A new effect in GR: “Frame dragging”

local inertial frame is “dragged” by dynamical space-time

local frame rotates relative to the distant universe

Drag is measured in the solar system

It becomes extreme in spinning black holes



Apache Point Observatory lunar laser ranging

Gravity Probe- B

Rotation in Quantum Mechanics

Standard elementary particles live in classical space

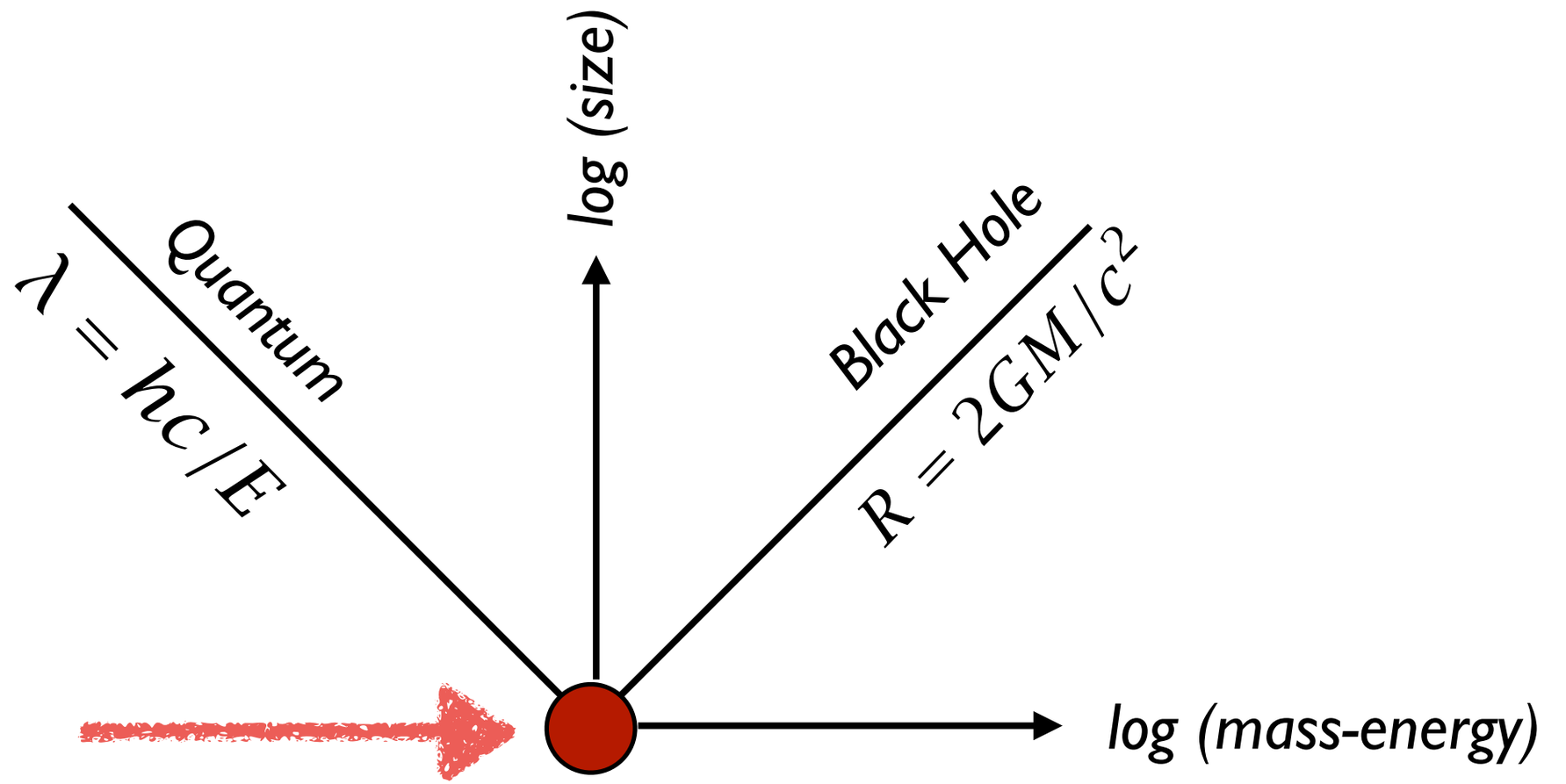
Spin is defined with respect to local inertial frame

Rotation is defined even for infinitesimal distances

But this story breaks down at the Planck scale

Planck scale: General Relativity meets Quantum Mechanics

At the Planck scale, geometry has to be fundamentally different



Local rotation cannot be defined below the Planck length

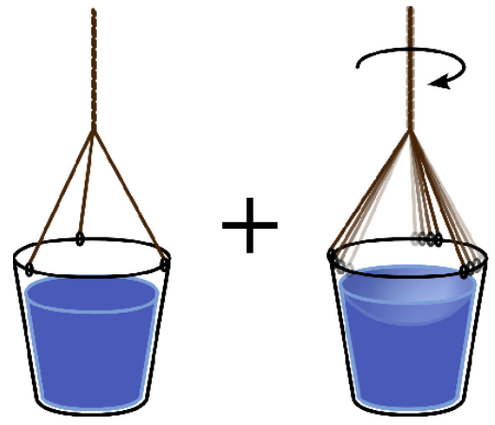
Planck length ~ 10^{-35} meters

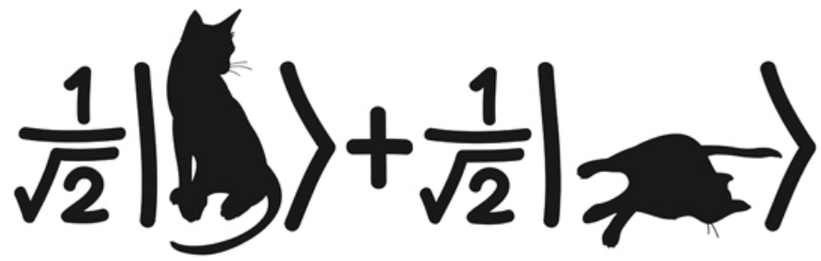
$$l_P \equiv ct_P \equiv \sqrt{\hbar G/c^3}$$

Planck mass ~ 10^{19} proton masses

$$m_P = \sqrt{\hbar c/G}$$

No Absolute Rotation at the Planck Scale





Extrapolate a Newton bucket to Planck length and mass

Gravity and frame dragging ~ black hole

Indeterminacy and spin ~ quantum particle

Indeterminate spin drags the inertial frame

The local inertial frame is a quantum superposition

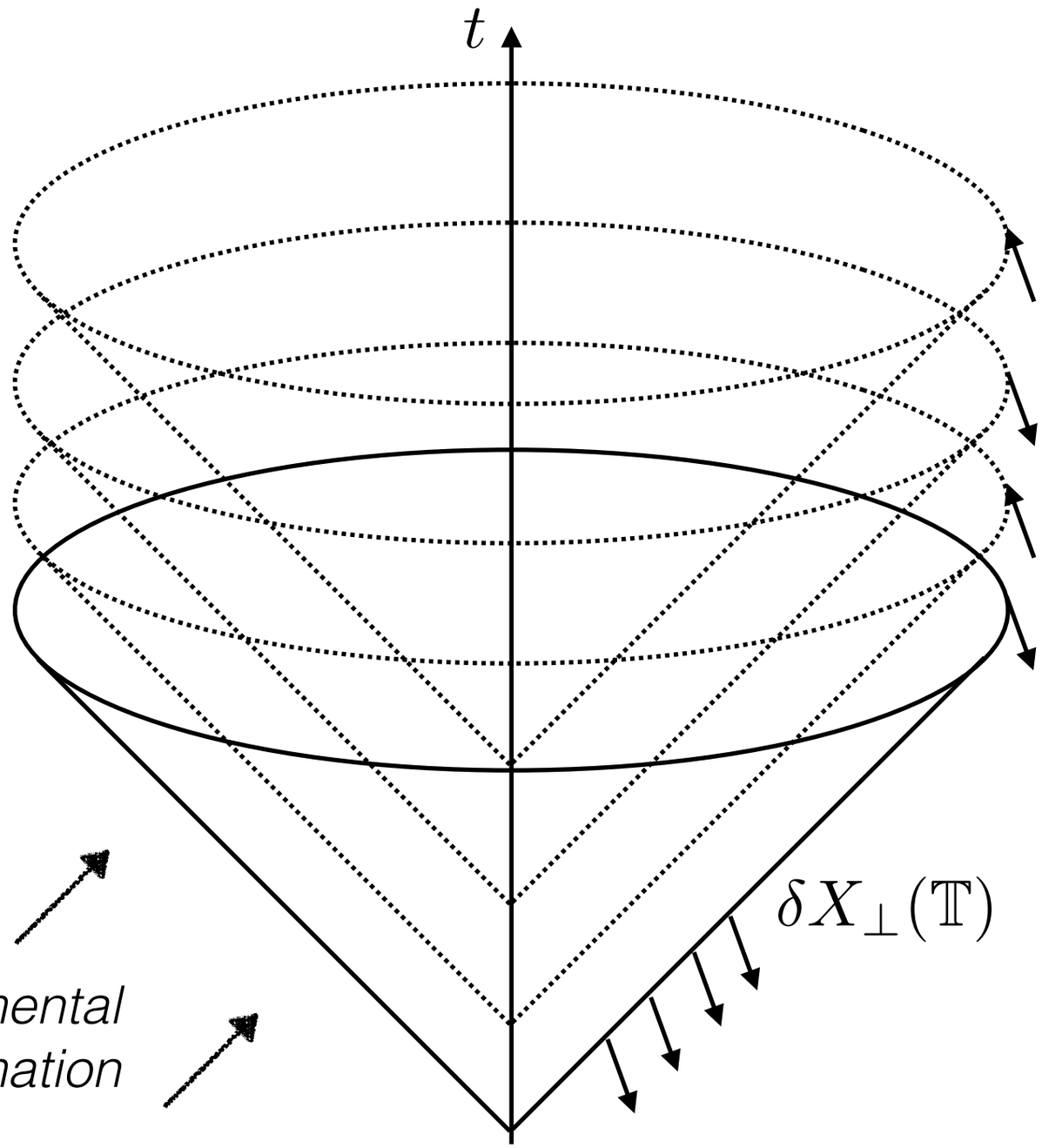
Rotation and direction emerge only statistically, in larger systems

Implies new, exotic nonlocal correlations, not in standard theory

Exotic nonlocal correlations can be computed in a statistical model

A Covariant Statistical Model for How Directions in Space-Time Emerge from the Planck Scale: Light Cone Twists

world line of observer



Correlations are causally local, but create spooky entanglement on spacelike surfaces

Random displacement on each light cone ~1 Planck time apart

Environmental Information

Projection of state by an observer => transverse displacements on each light cone

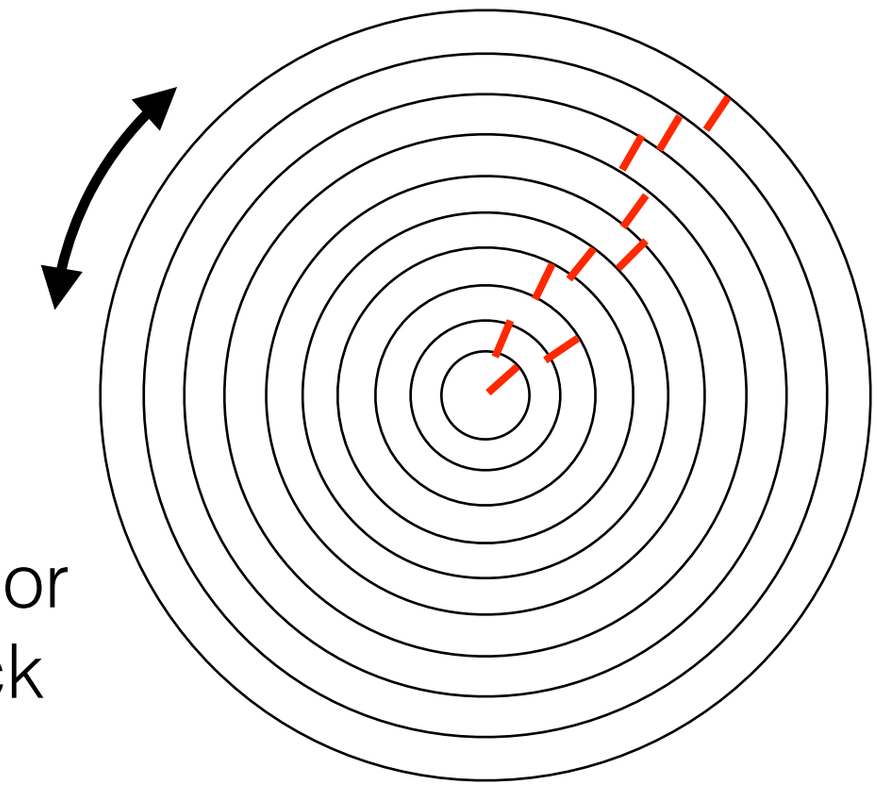
https://arxiv.org/abs/1607.03048

Exotic rotational fluctuations on spacelike surfaces

"Twists" of inertial frame

~ Planck random walk in transverse position

Mean rotation vanishes, mean square does not



Each "shell" jitters relative to the one next to it, or previous to it, by one Planck length each Planck time

Jitter is inherited by transversely propagating light

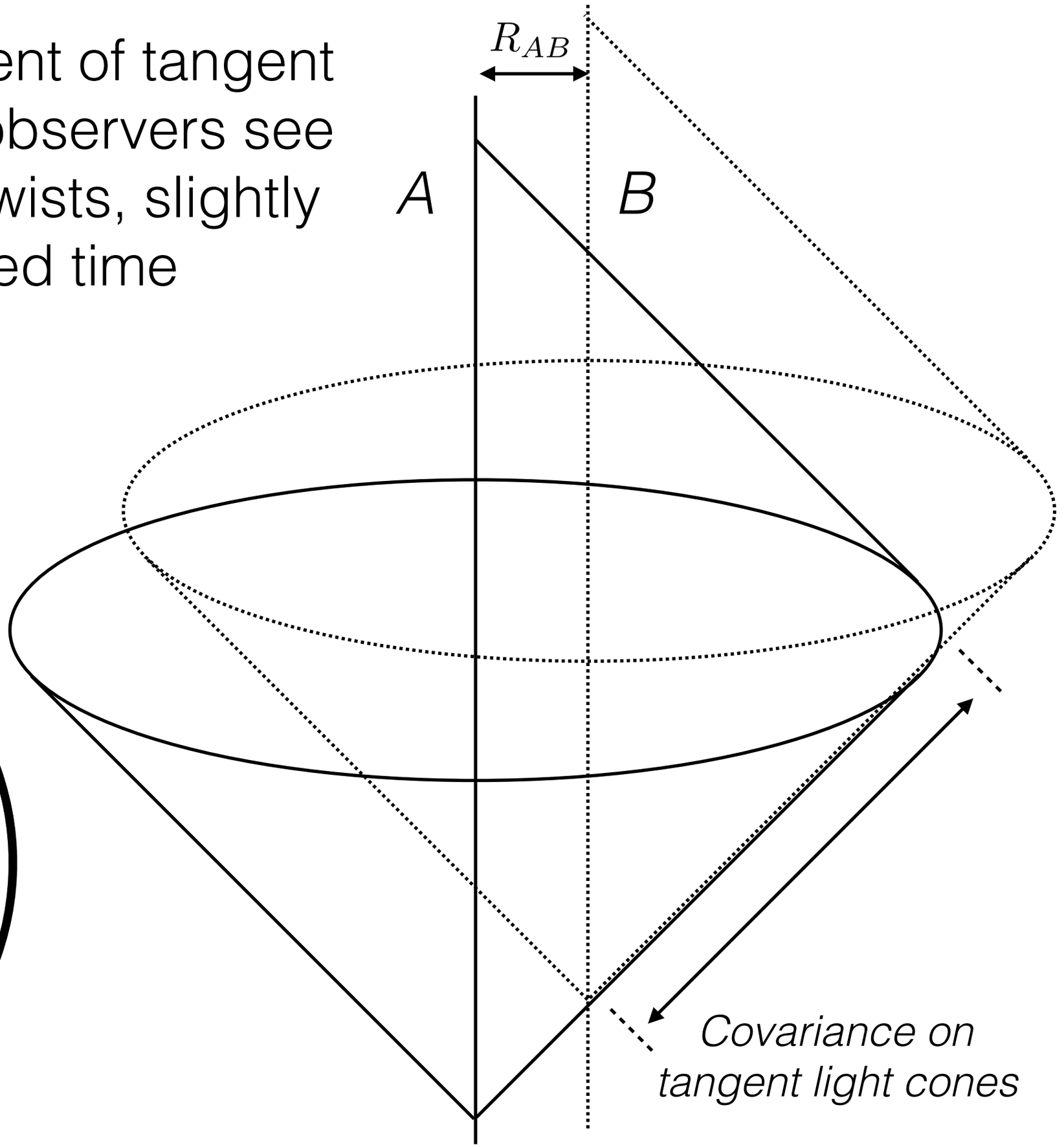
Directional fluctuations on large scales get smaller:

$$\langle \Delta\theta_P^2 \rangle_R \approx \langle \hat{x}_\perp^2 \rangle_R / R^2 = \ell_P / R$$

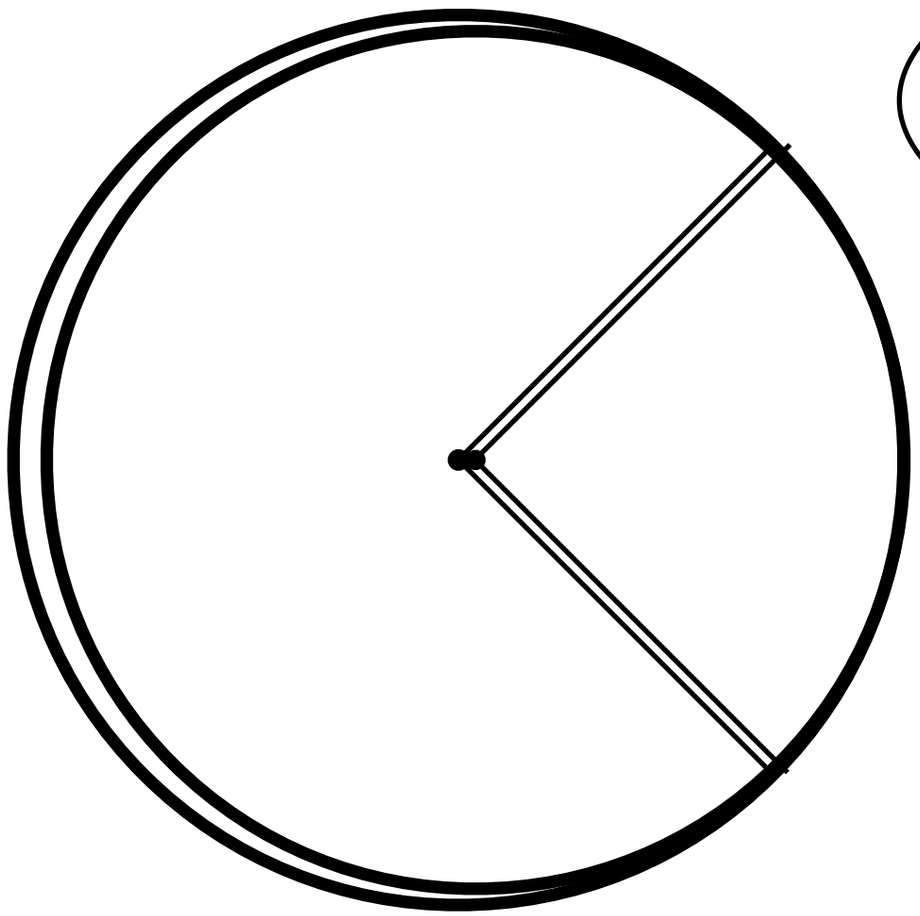
And rotational fluctuations on larger scales get slower:

$$\langle \omega_i^2(R) \rangle \approx c^2 \ell_P R^{-3}$$

"spooky" entanglement of tangent light cones: nearby observers see the same rotational twists, slightly displaced in measured time



Spacelike slices for nearby observers

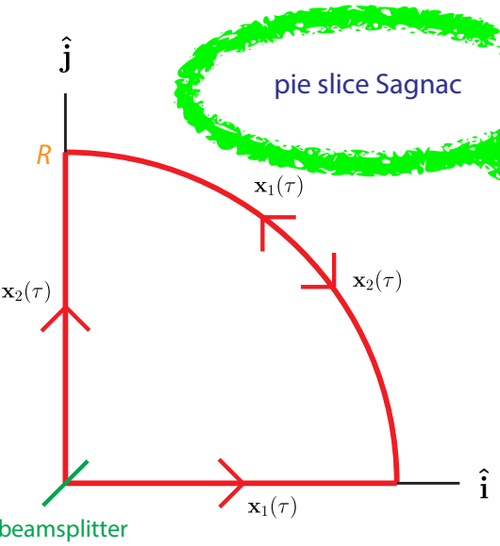


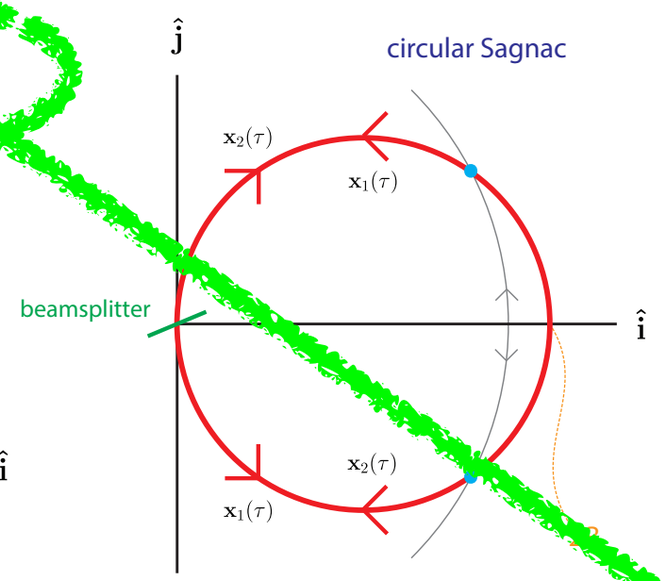
An Experiment that Measures Planck Scale Correlations: the Fermilab Holometer

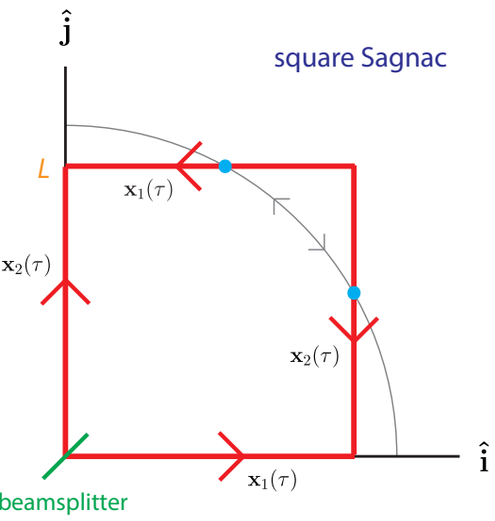
Proven instrument: http://arxiv.org/abs/1512.01216, PRL in press

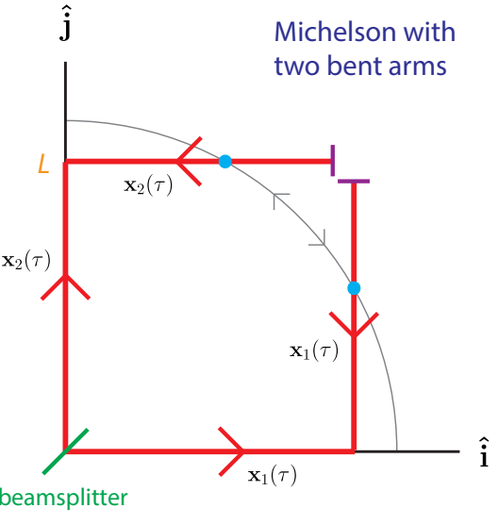
Reconfiguration ("twist") now underway will be sensitive to rotation (ICHEP talk by Chris Stoughton)

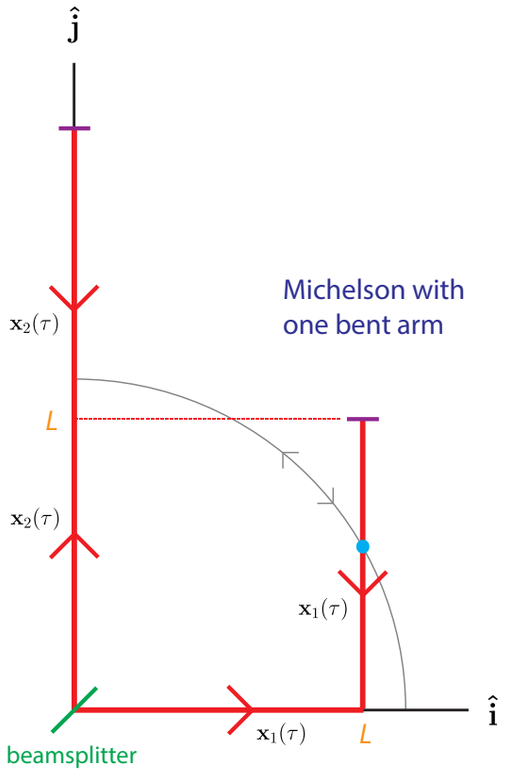
Examples of Interferometer Light paths in 2D and in 1+1D

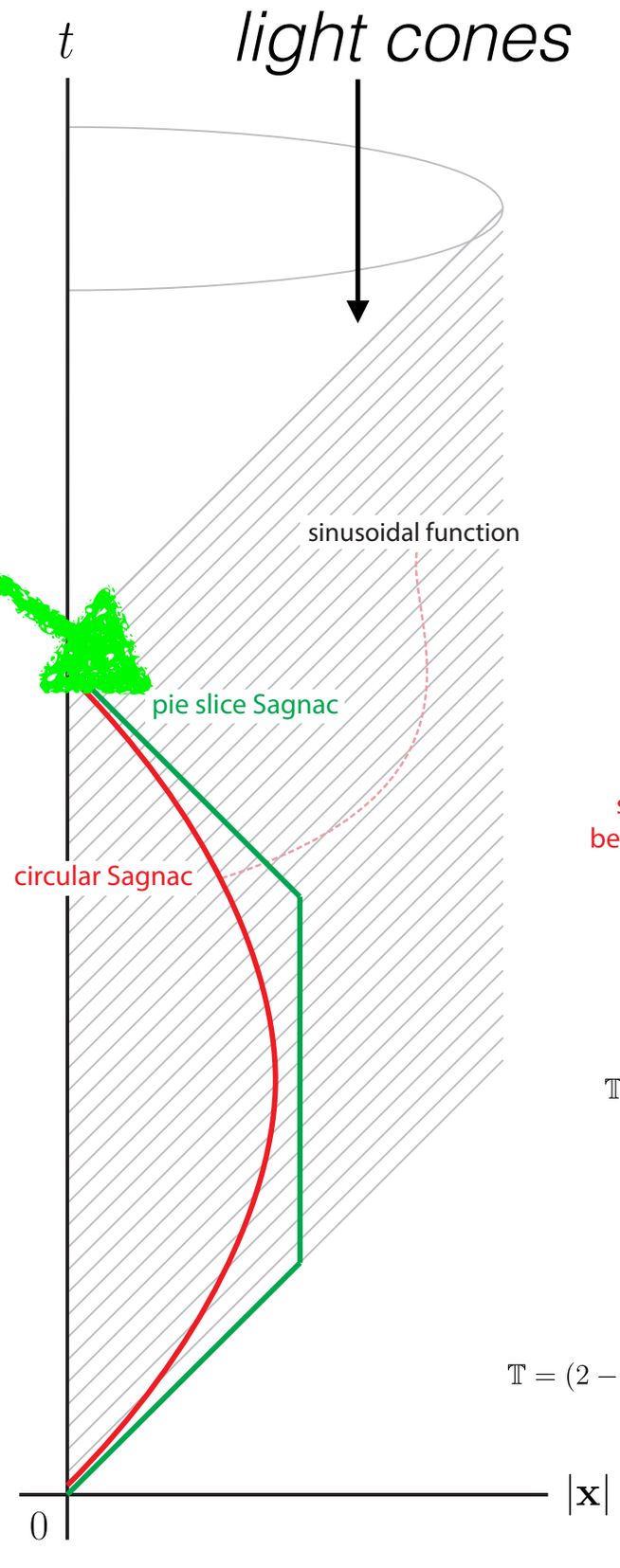


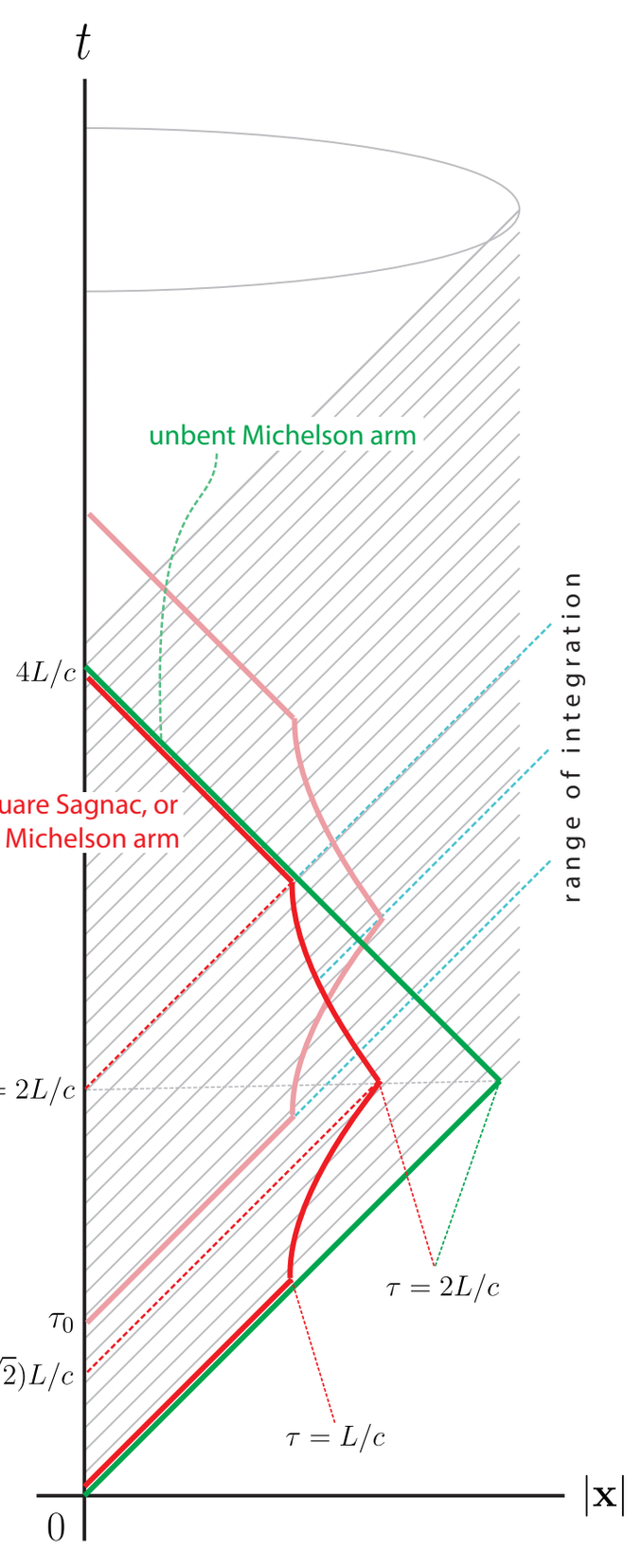




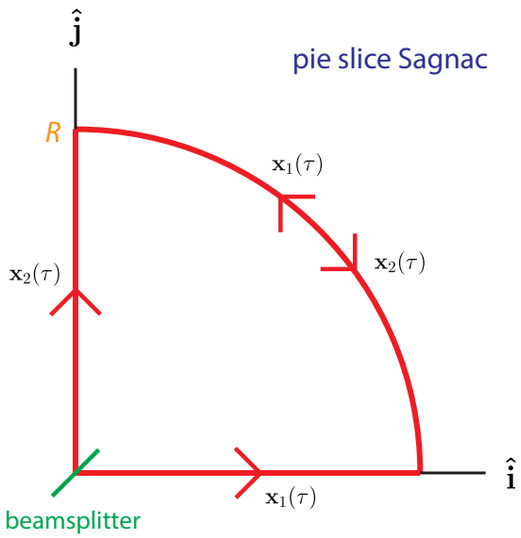


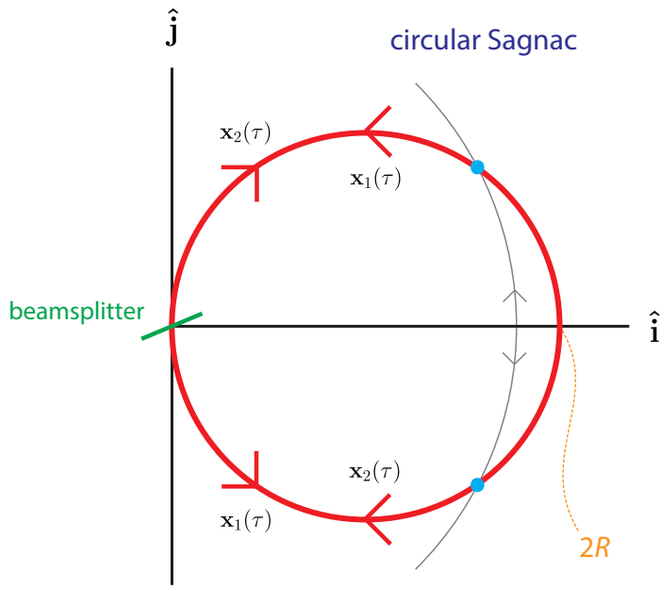


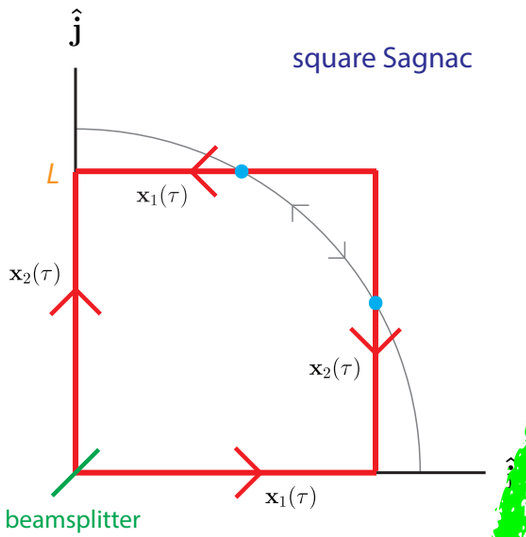


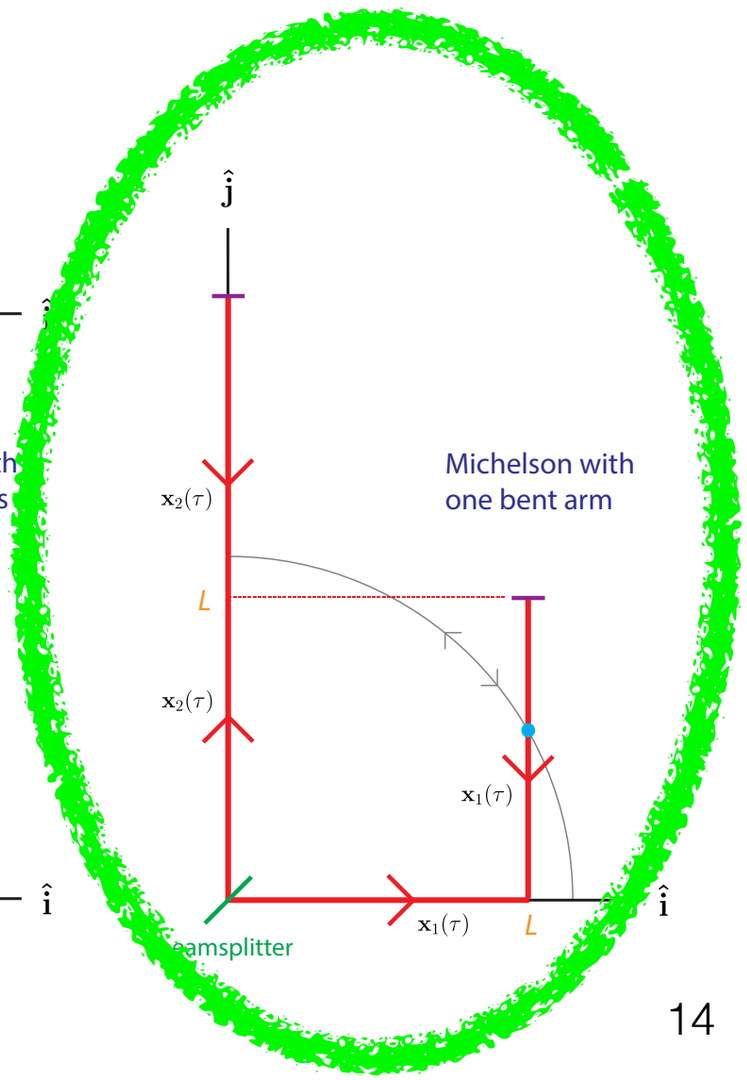


Light paths in various interferometer layouts







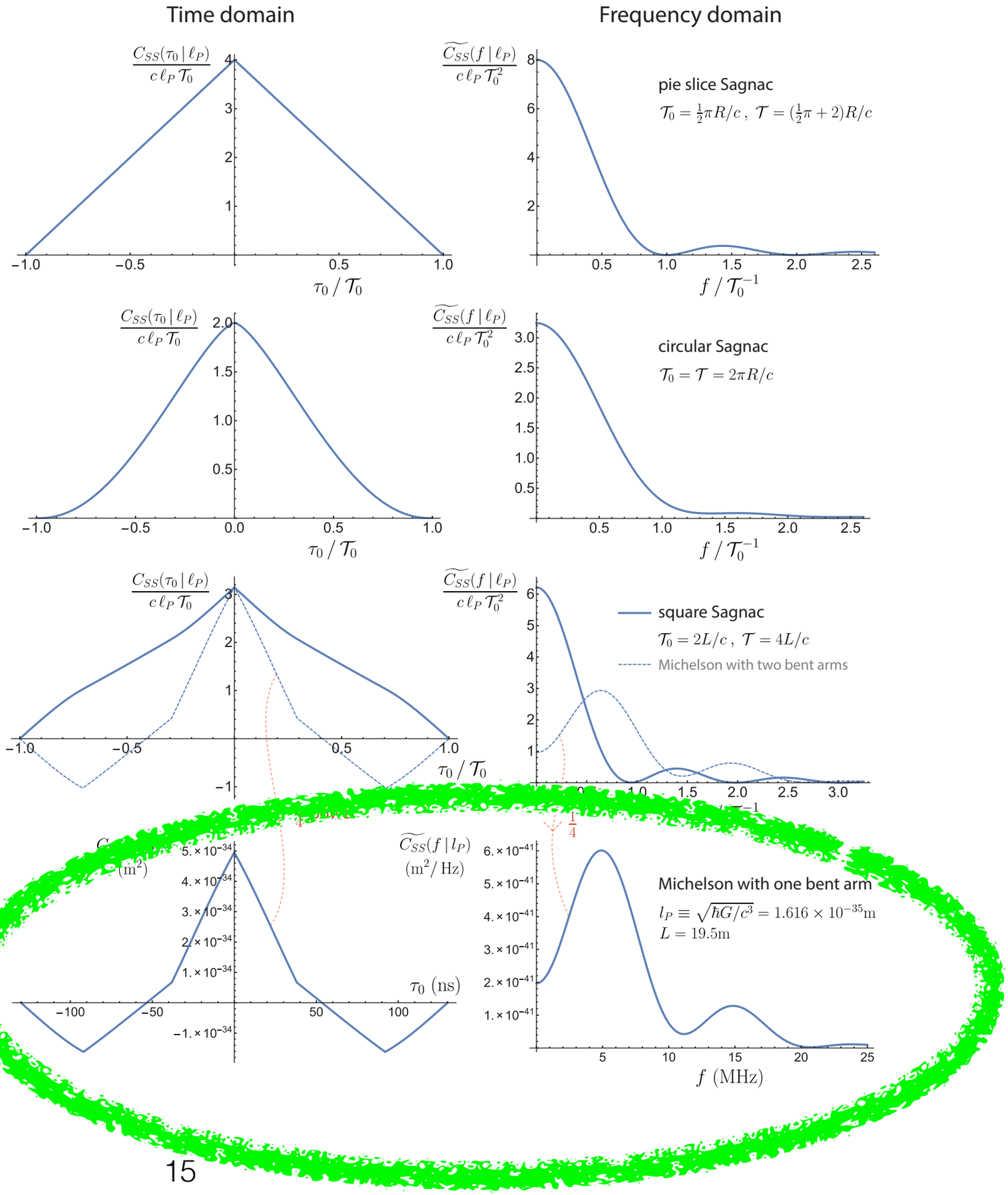


Currently under construction at Fermilab: bent Michelson layout, based on reconfiguration of Fermilab Holometer parts

Exact predictions for exotic correlations in signals of various interferometer layouts

Planck length is the only parameter

Configuration now being built: projected measurement in less than a day



Rotational Fluctuations and Cosmic Acceleration

Centrifugal acceleration from rotational fluctuations statistically mimics cosmic acceleration at the scale where

$$\langle \omega(R_\Lambda)^2 \rangle = H_\Lambda^2 = \Lambda/3$$

$$m_\Lambda/m_P \approx (R_\Lambda/l_P)^{-1/2} \approx (H_\Lambda t_P)^{1/3}$$

~ strong interaction scale: *m*~ 200 MeV, *R*~ 60 km

Twists of strong interaction vacuum “shake space apart” below confinement scale

Cosmological constant from scales of known physics

acceleration timescale ~ the same combination of constants that determines a stellar lifetime (—> why now)

Summary

Planck scale indeterminacy makes the inertial frame fluctuate

A statistical model based on causality predicts exotic nonlocal rotational correlation in the signal of any interferometer

The prediction can be tested with a transfiguration of the Fermilab Holometer now under construction

If they exist, centrifugal fluctuations of the strong interaction vacuum could account for cosmic acceleration