Title: Measuring Distance with Acceleration-assisted Entanglement Harvesting

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Abstract: We show that entanglement harvested from a quantum field by interaction with local detectors undergoing anti-parallel acceleration can be used to measure the distance of closest approach between the two detectors. Information about the separation is stored nonlocally in the phase of the joint state of the detectors after the interaction; a single detector alone contains none. We model the detectors as two-level quantum systems accelerating uniformly through the Minkowski vacuum
while interacting for a short time with a massless scalar field. This interaction allows entanglement to be swapped locally from the field to the detectors. Although each detector alone sees the same thermal spectrum (due to Unruh radiation), the joint state between them may be entangled. In the vicinity of a critical distance of closest approach between the detectors, the phase of the entangled state depends sensitively on the distance. We contrast this with the case of parallel acceleration, in which no such critical distance exists, and we discuss the connection of this case with entanglement harvested from an expanding universe.

- Single detector:

$$A = \int_{-\infty}^{\infty} d\tau \int_{-\infty}^{\infty} d\tau' \, \eta(\tau)\eta(\tau') e^{-i\Omega(\tau-\tau')} D^{+}\big(x(\tau); x(\tau')\big)$$

A – probability of excitation

τ – proper time

η – window function governing interaction with field

Ω – energy gap between levels in detector

D^{+} – Wightman function

- Two Detectors

$$X = -\int_{-\infty}^{\infty} dt \int_{-\infty}^{t} dt' \, \eta(t)\eta(t') e^{-i\Omega(t+t')} \times \left[D^{+}\big(x_a(t); x_b(t')\big) + D^{+}\big(x_b(t); x_a(t')\big)\right]$$

X – amplitude for virtual particle exchange

t – coordinate time

Criterion for entanglement

A – probability of excitation

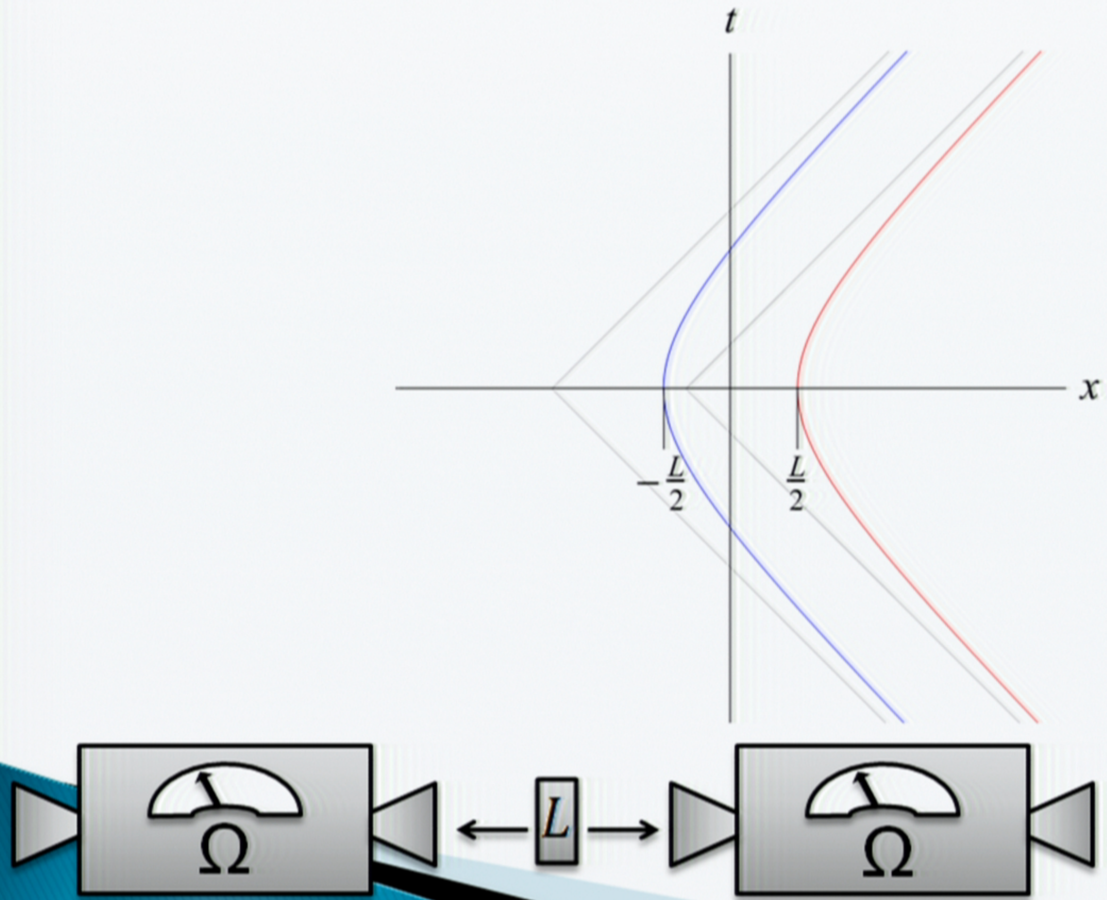
X – amplitude for virtual particle exchange

$$A = \int_{-\infty}^{\infty} d\tau \int_{-\infty}^{\infty} d\tau' \, \eta(\tau)\eta(\tau') e^{-i\Omega(\tau-\tau')} D^{+}\big(x(\tau); x(\tau')\big)$$

$$X = -\int_{-\infty}^{\infty} dt \int_{-\infty}^{t} dt' \, \eta(t)\eta(t') e^{-i\Omega(t+t')} \times \left[D^{+}\big(x_a(t); x_b(t')\big) + D^{+}\big(x_b(t); x_a(t')\big)\right]$$

$$|X| > A$$

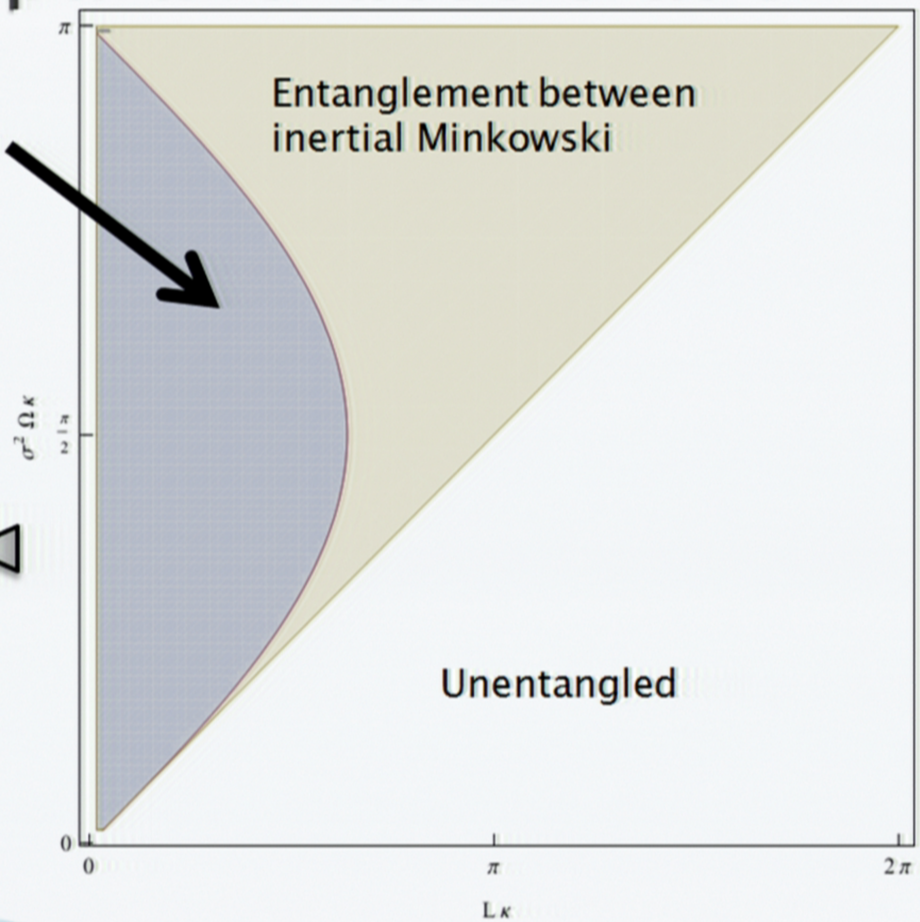
First case – parallel acceleration



First case – parallel acceleration

Entanglement in Rindler

$$\Omega = E_e - E_g$$

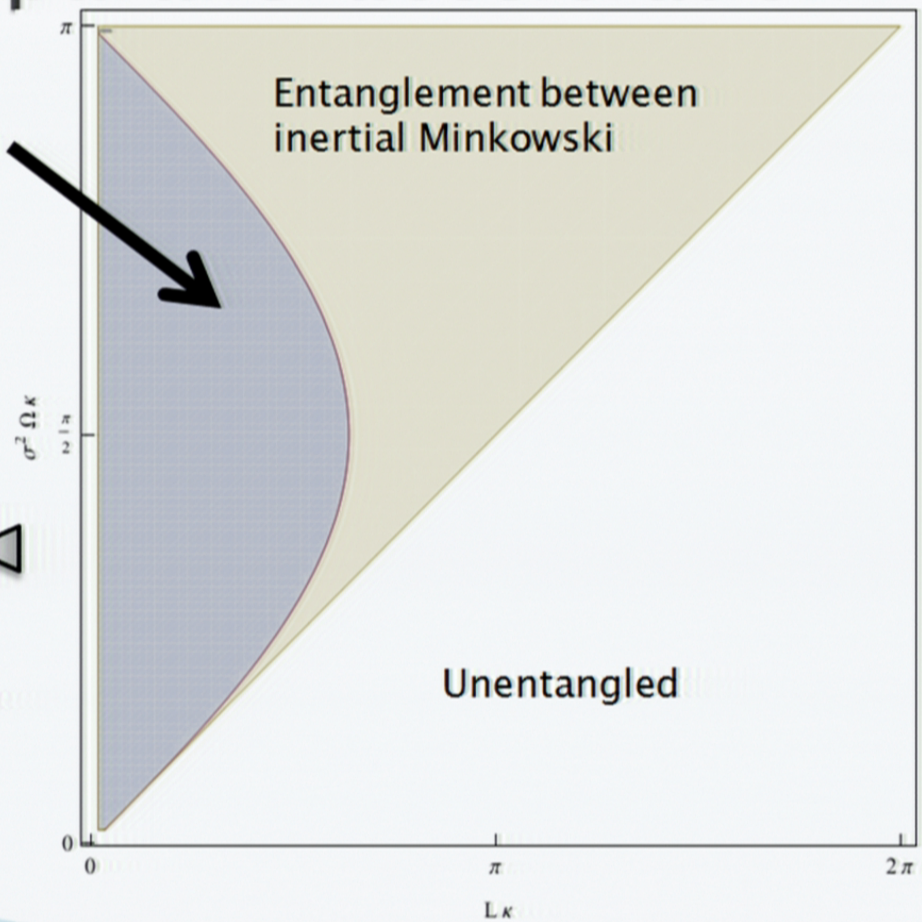


First case – parallel acceleration

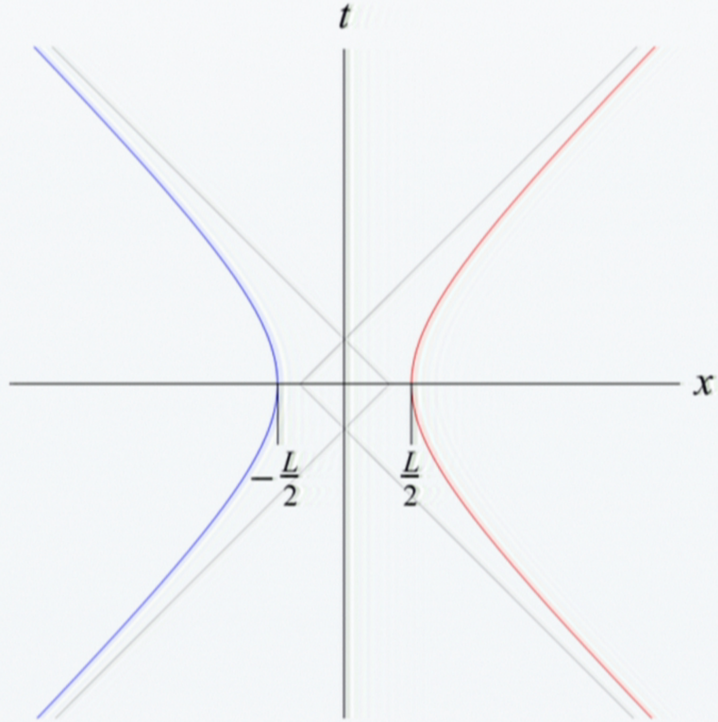
Entanglement in Rindler

$$\Omega = E_e - E_g$$

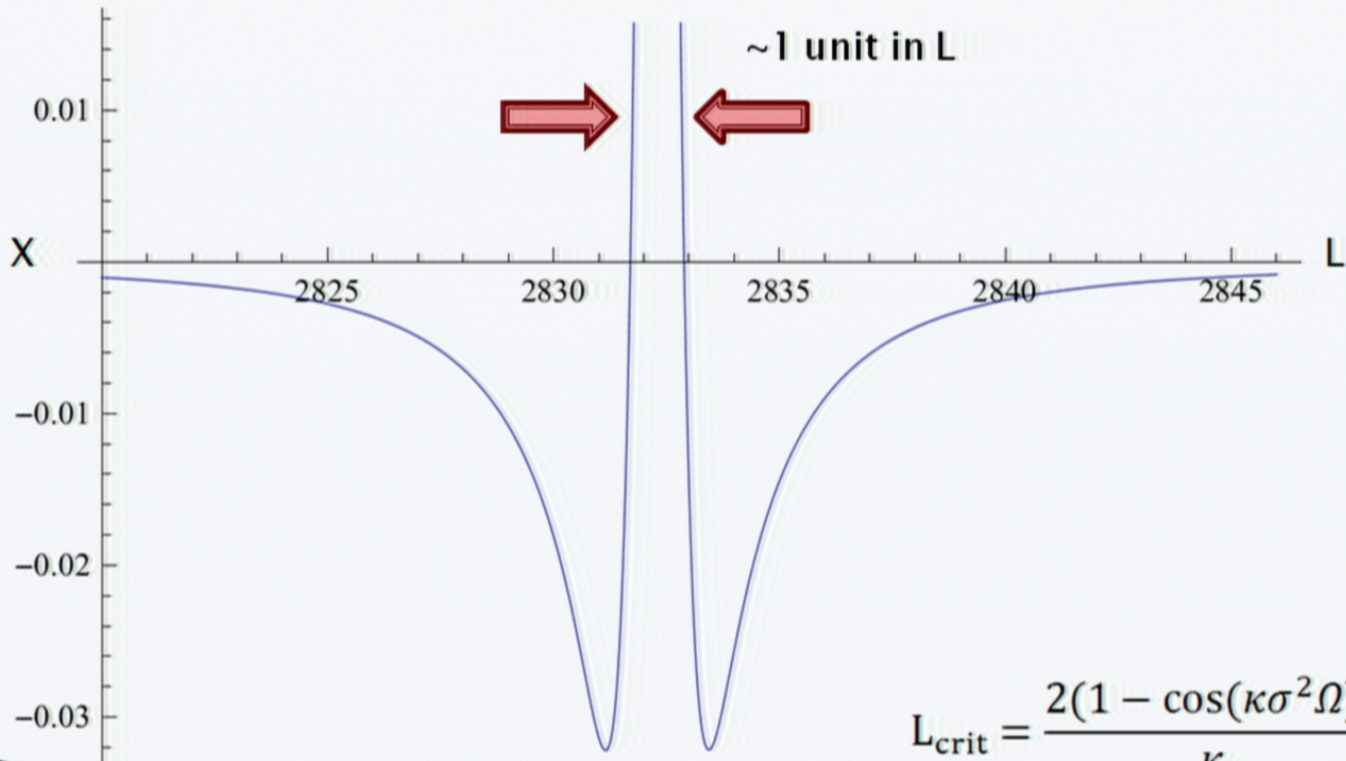
n.b., same as de Sitter space and Gibbons-Hawking



Anti-parallel acceleration



Entanglement based metrology



$$L_{\text{crit}} = \frac{2(1 - \cos(\kappa\sigma^2\Omega))}{\kappa}$$

Ω=1000, κ=0.001, σ=1

Detecting the sign flip…

$$\rho = \begin{pmatrix} \langle X|X\rangle^2 & & & -X^* \\ & A_a & \langle A_b|A_a\rangle & \\ & \langle A_a|A_b\rangle & A_b & \\ -X & & & 1-2A \end{pmatrix}$$

$$\langle \sigma_x \otimes \sigma_x \rangle = -2\mathrm{Re}(X) + 2\mathrm{Re}(\langle A_a|A_b\rangle)$$

$$\langle \sigma_y \otimes \sigma_y \rangle = 2\mathrm{Re}(X) + 2\mathrm{Re}(\langle A_a|A_b\rangle)$$

$$4\mathrm{Re}(X) = -\langle \sigma_x \otimes \sigma_x \rangle + \langle \sigma_y \otimes \sigma_y \rangle$$

- Perform local measurements in x or y, then send the information to the home planet
- When the same bases were chosen, construct an estimate for 4Re(X)

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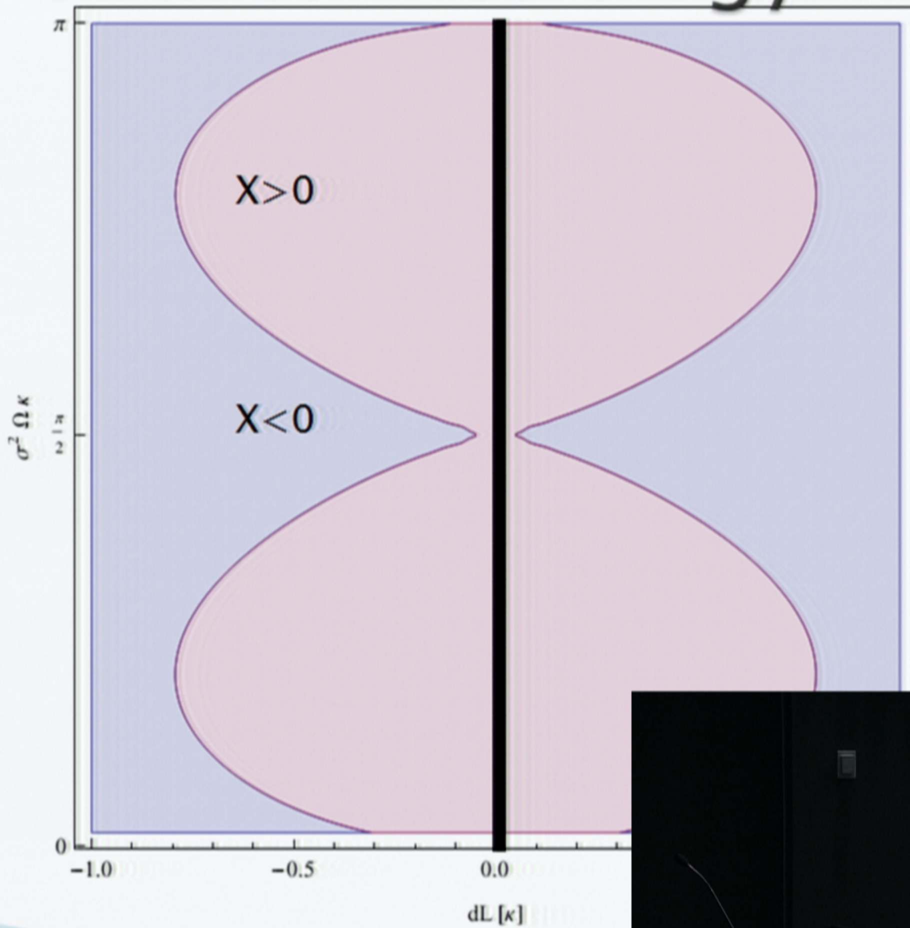
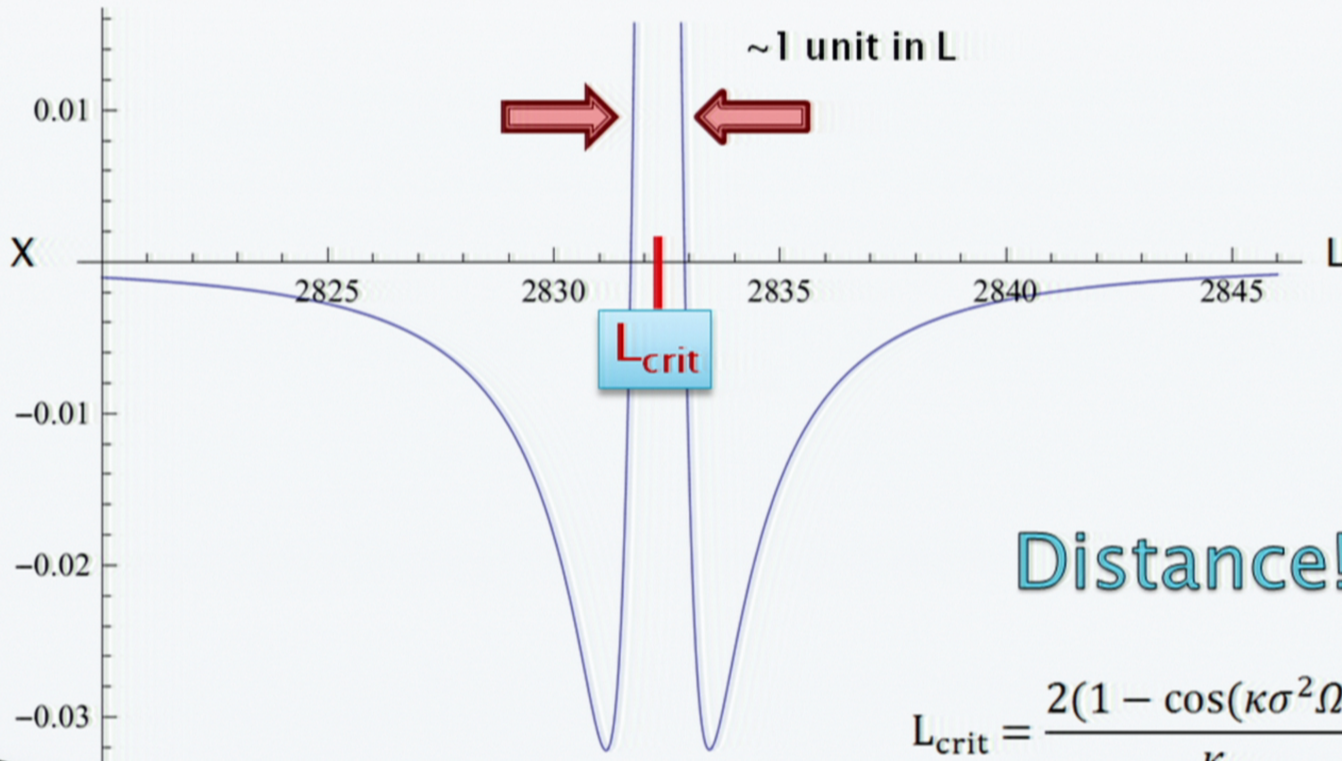
Entanglement based metrology

$$L_{crit} = \frac{2(1-\cos(\kappa\sigma^2\Omega))}{\kappa}$$

$$dL = L - L_{crit}$$



Entanglement based metrology



Distance!

$$L_{crit} = \frac{2(1 - \cos(\kappa\sigma^2\Omega))}{\kappa}$$

$\Omega=1000, \kappa=0.001, \sigma=1$

Entanglement based metrology

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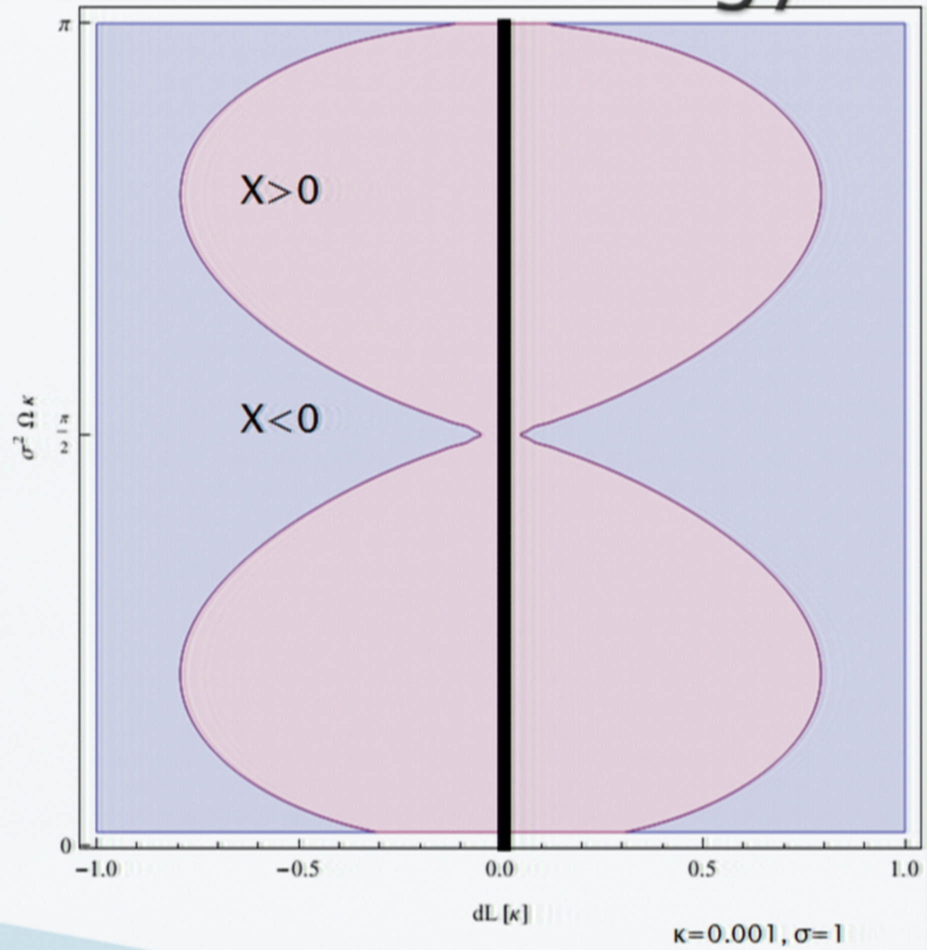
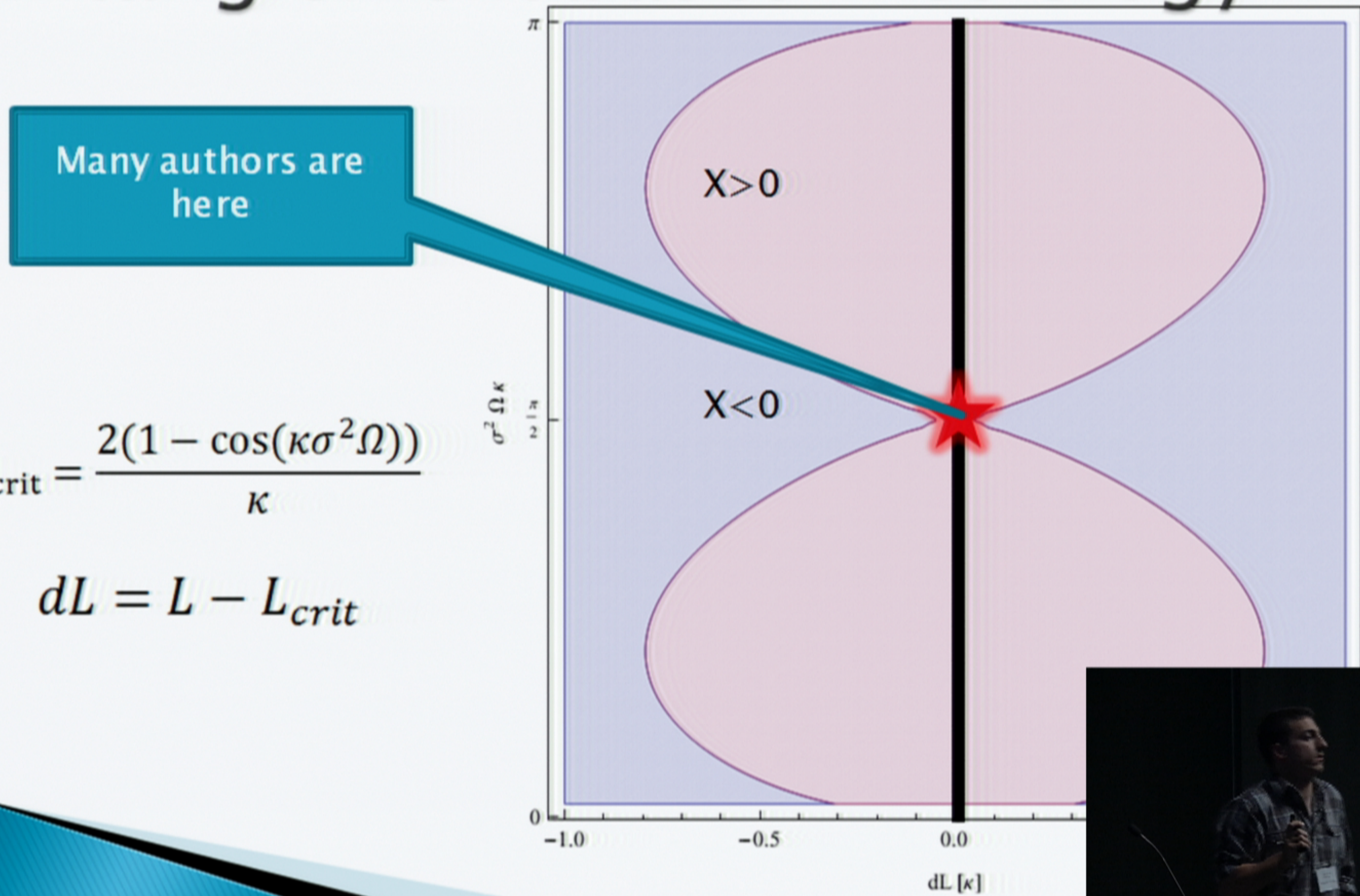


Entanglement based metrology



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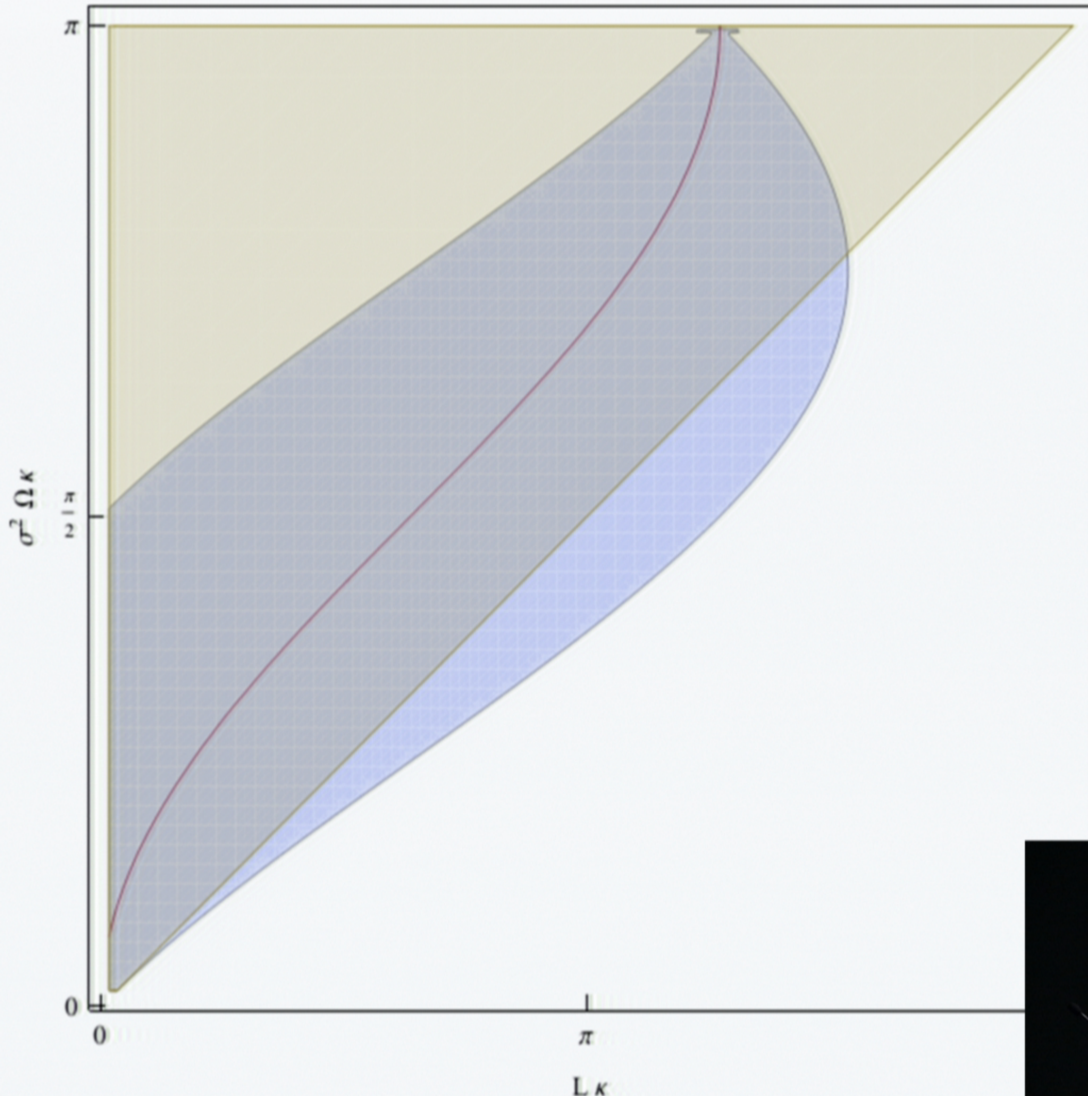
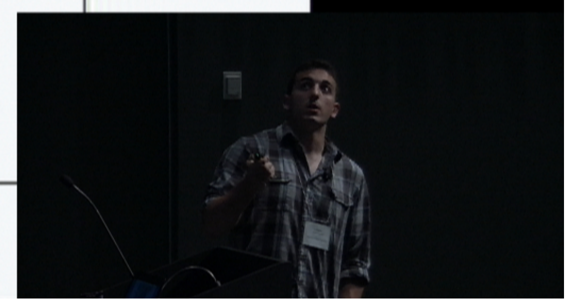
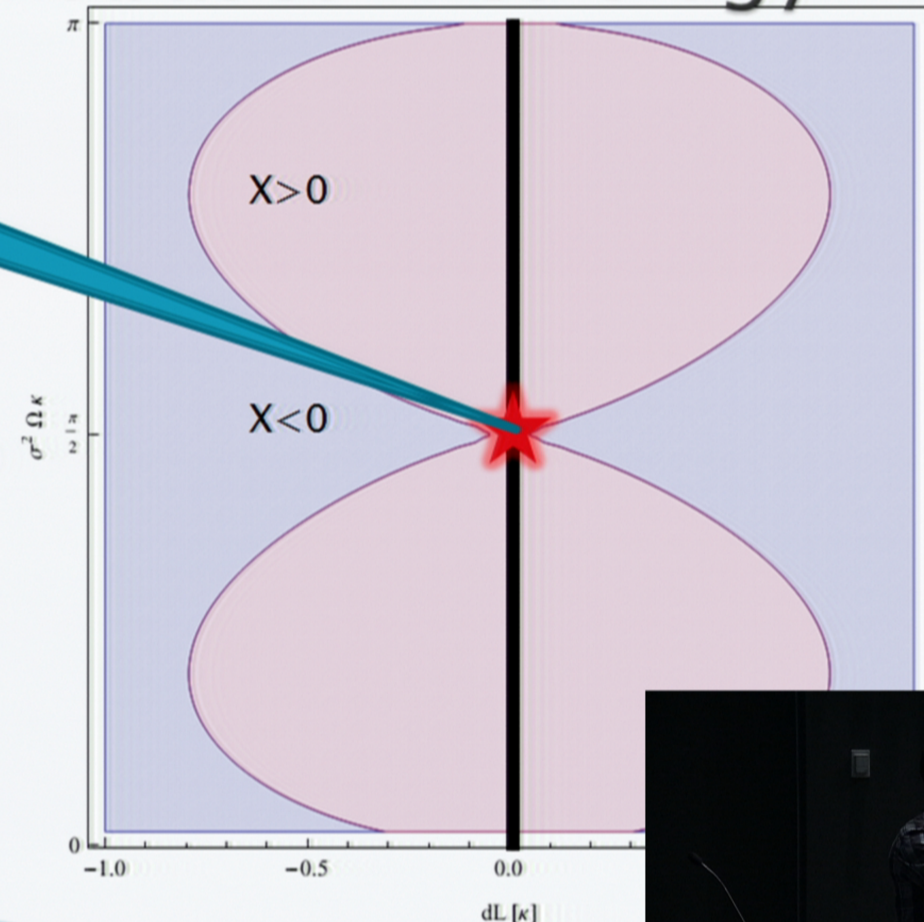

π
π/2
0
0
π
L κ
σ² Ω κ



Entanglement based metrology

Many authors are here



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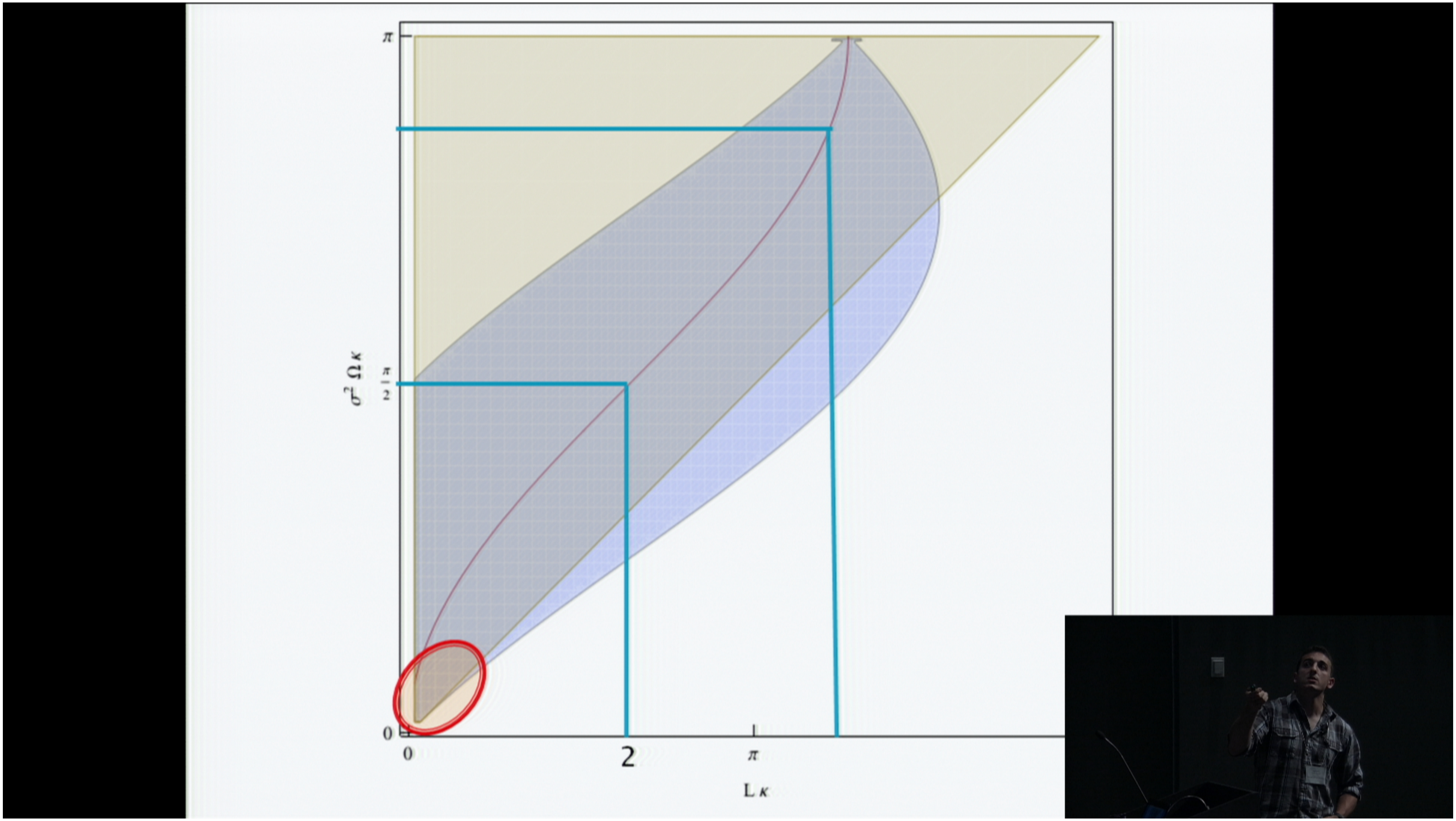
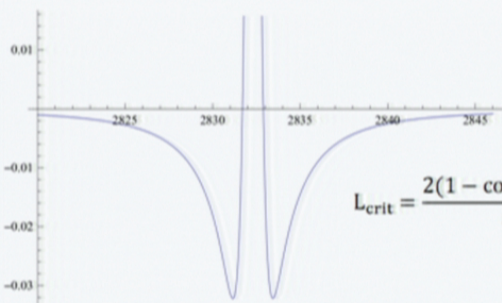
$$dL = L - L_{crit}$$



π
$\frac{\pi}{2}$
0
$\sigma^2\,\Omega\,\kappa$
0
2
π
L κ

Thank you!

- Use entanglement to probe distances in spacetime
  - Critical distance at which we hit resonance
    - Allow for uncertainty in distance and/or frequency



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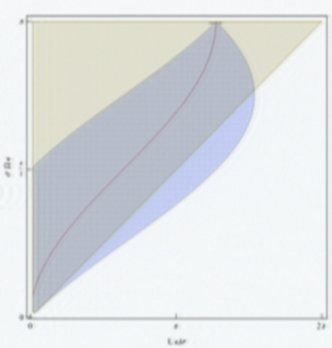

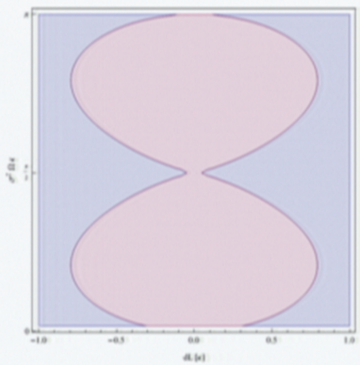

Questions?