Gravity and Decoherence:

the double slit experiment revisited

Joseph Samuel
Raman Research Institute
Bangalore, India

1. Introduction: Gravity and Quantum Theory

2. Gravity and Decoherence

3. The Double Slit Experiment

4. Proposed Experiments E1 and E2

5. Mathematical Argument

6. Conclusion

GRAVITY and QUANTUM THEORY

What is the relation between them?

Gravity in the large QM in the small

Quantum Gravity: New theories which agree with GR at low energies

Explore the short distance behaviour of gravity

String Theory, Loop Quantum Gravity
Causal Sets, Non-Commutative Geometry …

lack of experimental guidance

Internal Consistency Aesthetics

GRAVITY and QUANTUM THEORY

What is the relation between them?

Alternative strategy

Understand the theories we already have
Quantum Field theory, GR by thought experiments
which push both theories
to confront each other

Explore the long distance behaviour of Quantum systems
Gravitational Quantum Physics?

GRAVITY AND DECOHERENCE

Gravity spoils quantum coherence Penrose, Diosi
Feynman Chapel Hill 1957

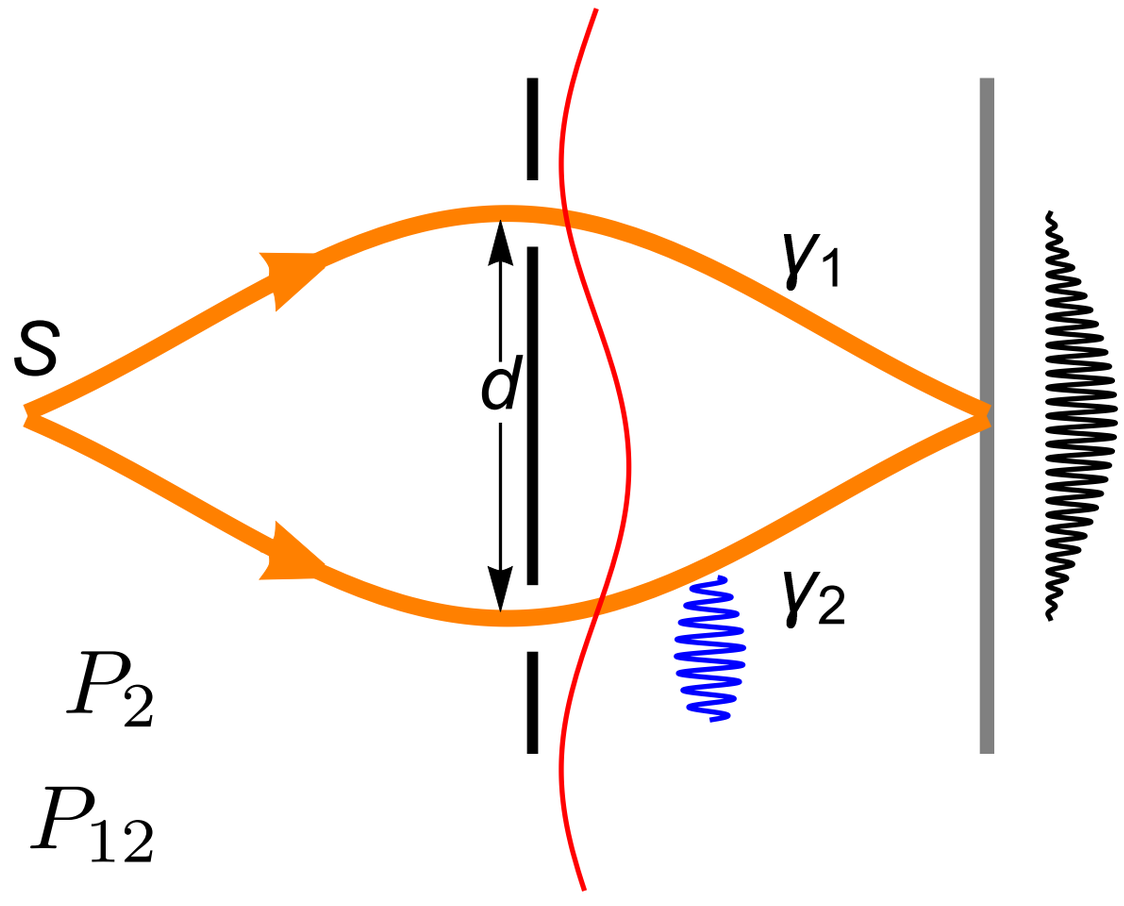
"I would like to suggest that it is possible that quantum mechanics fails at large distances and for large objects, it is not inconsistent with what we do know. If this failure of quantum mechanics is connected with gravity, we might speculatively expect this to happen for masses such that $GM^2/c^2 = 1$, or M near 10^{-5} grams."

Standard approach in Newtonian gravity
Rimini Weber Ghirardi spontaneous collapse

Penrose interpretation One graviton difference

THE DOUBLE SLIT EXPERIMENT

THE ONLY MYSTERY
OF QUANTUM PHYSICS: RP FEYNMAN



$P_1 \quad P_2$

P_{12}

$P_{12} \neq P_1 + P_2$

$p \sim \hbar/d$

Probabilities of Exclusive events add in the classical world

PROPOSED EXPERIMENTS E1 E2

E1: Double slit experiment in a thermal environment

E2: Double slit experiment in an accelerated frame

Analyse both experiments using only known physics:
Find in E1: thermal fluctuations of the electromagnetic field cause decoherence in the electron double slit experiment
E2: Vacuum fluctuations of inertial observer appear thermal to the accelerated observer loss of coherence

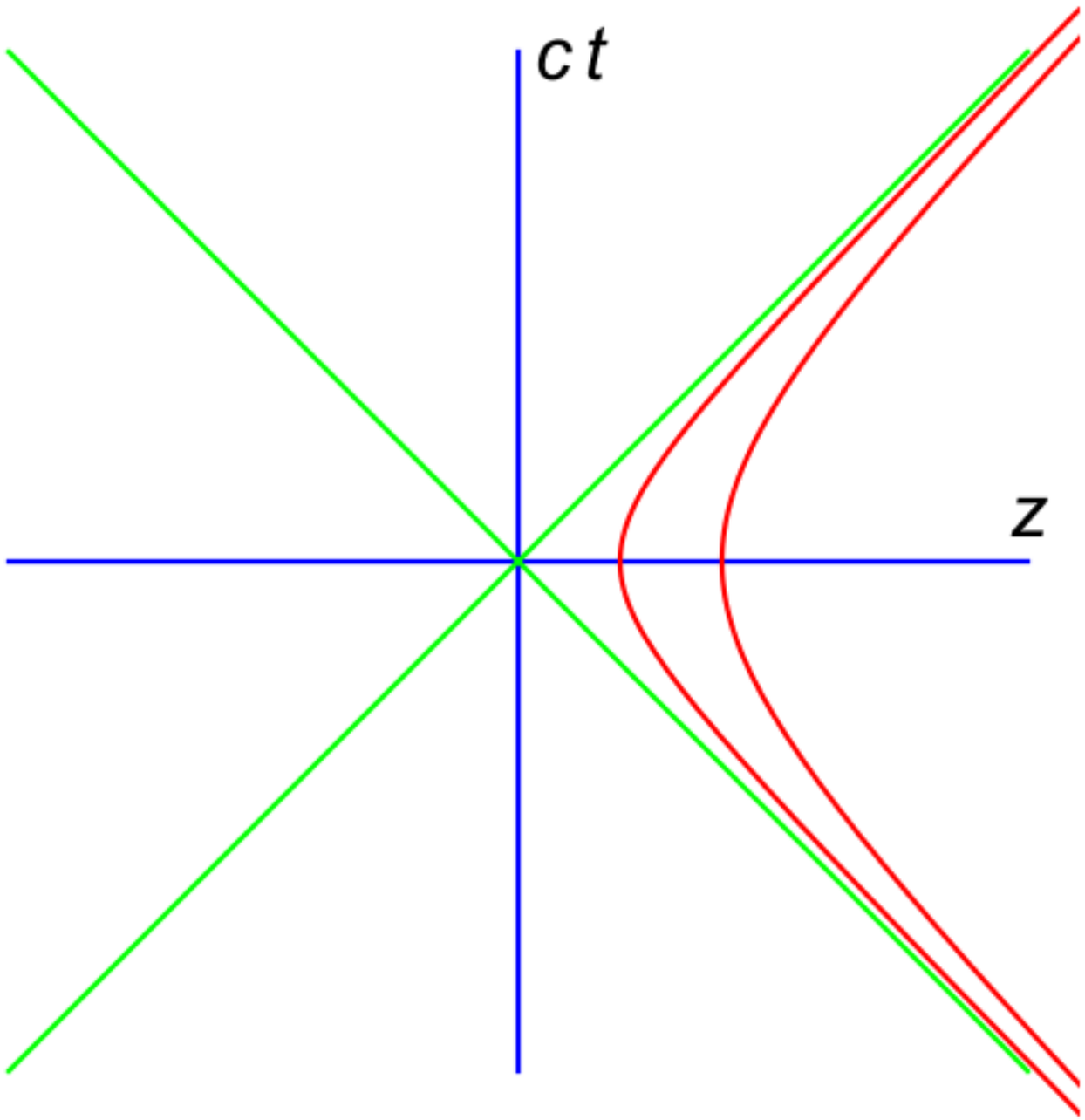
The analysis can be done physically as well as mathematically
Physical argument: scattering off ambient photons spoils the interference pattern. Field correlations die out as

$$\exp -\frac{(x-x')}{\lambda_W}$$

At room temperature about 20 microns

$$\lambda_W = \frac{\hbar c}{k_B T}$$

At 3^0 K, about 2mm



RINDLER OBSERVER

MATHEMATICAL ARGUMENT

Without em field

$$\Psi_1 \quad \Psi_2$$

$$|\Psi_1| = |\Psi_2|$$

$$I = \Psi_2^* \Psi_1 + \Psi_1^* \Psi_2$$

visibility =unity

With em field

$$\Psi_1 \rightarrow \Psi_1 \exp \frac{ie}{\hbar c} \int_{\gamma_1} \mathbf{A}(\mathbf{x}) \mathbf{dx}$$

$$I \rightarrow < \mathcal{W} > I$$

$$\mathcal{W} = \exp \frac{ie}{\hbar c} \int_{\gamma} \mathbf{A}(\mathbf{x}) d\mathbf{x}$$

visibility is thermal average of wilson loop

$$\mathbf{A}(\mathbf{x}) = \Sigma_l [\mathbf{u}_l(\mathbf{x})\, a_l + \overline{\mathbf{u}_l}(\mathbf{x})\, a_l^\dagger]$$

Expand the em field in modes

MATHEMATICAL ARGUMENT

$$< \mathcal{W} >= \Pi_l \exp i[a_l \alpha_l + a_l^\dagger \overline{\alpha}_l],$$

α_l is the form factor of the loop

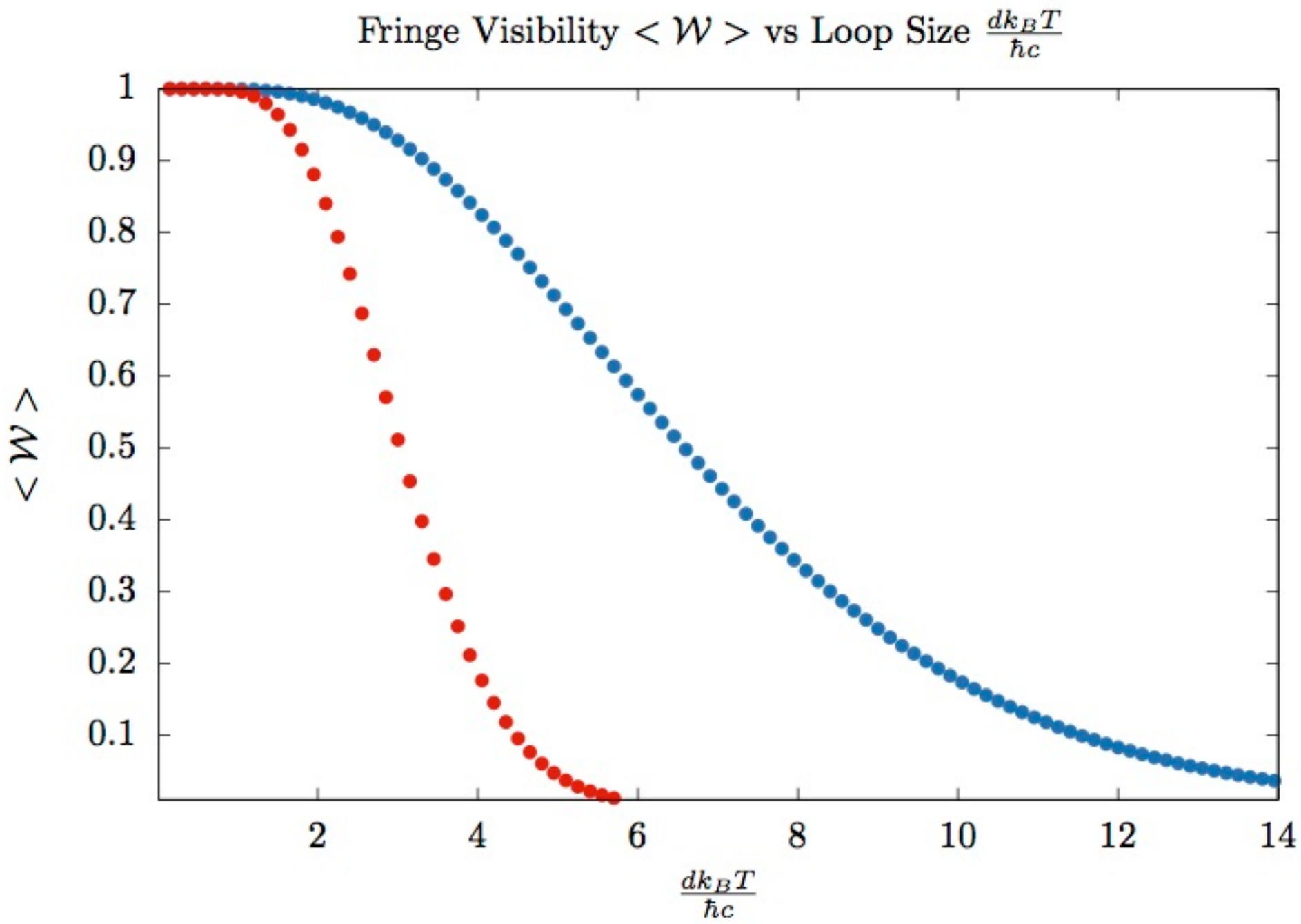
$$\alpha_l = \oint \mathbf{u}_l . d\mathbf{x}$$

Compute Thermal Average (easy) Find

$$< \mathcal{W} >= \exp\,[-\frac{e^2}{2\hbar c} \sum_l (|\alpha_l|^2 \coth \frac{\hbar\omega_l}{2k_B T})]$$

For E2 find the same with the mode functions of Rindler and

$$T = g \frac{\hbar}{2\pi k_B c}.$$



Information being carried away by soft photons

Fluctuation Dissipation Relation

CONCLUSION

SIMPLE MODEL FOR GRAVITY INDUCED DECOHERENCE

EINSTEIN EQUIVALENCE PRINCIPLE RELATES GRAVITY TO ACCELERATION

CONSONANT WITH FEYNMAN PENROSE DIOSI EXPECT SIMILAR DECOHERENCE EFFECTS FOR STATIC OBSERVERS OUTSIDE THE EVENT HORIZON OF A BLACK HOLE

OTHER MODELS ZYCH DECOHERENCE IS REVERSIBLE
E1: PRACTICAL AND FUNDAMENTAL DECOHERENCE
E2: SAME CRITERIA
DIVING INTO

FINE POINTS : BUNDLES OF PATHS VACUUM EFFECTS

REPLACE EM WITH GRAVITY FIND ANSWER TO FEYNMAN
GRAVITY DECOHERES QUANTUM SYSTEMS EFFECT LARGER FOR LARGER SYSTEMS AND MORE STRONGLY COUPLED ONES

CONCLUSION

SIMPLE MODEL FOR GRAVITY INDUCED DECOHERENCE

EINSTEIN EQUIVALENCE PRINCIPLE RELATES GRAVITY TO ACCELERATION

CONSONANT WITH FEYNMAN PENROSE DIOSI EXPECT SIMILAR DECOHERENCE EFFECTS FOR STATIC OBSERVERS OUTSIDE THE EVENT HORIZON OF A BLACK HOLE

OTHER MODELS ZYCH DECOHERENCE IS REVERSIBLE
E1: PRACTICAL AND FUNDAMENTAL DECOHERENCE
E2: SAME CRITERIA
DIVING INTO

Simplicio, Sagredo and Sagacio

CONCLUSION

SIMPLE MODEL FOR GRAVITY INDUCED DECOHERENCE

Uses only known physics

FINE POINTS : BUNDLES OF PATHS VACUUM EFFECTS

CONCLUSION

REPLACE EM WITH GRAVITY FIND ANSWER TO FEYNMAN
GRAVITY DECOHERES QUANTUM SYSTEMS EFFECT LARGER FOR LARGER SYSTEMS AND MORE STRONGLY COUPLED ONES

$$< \mathcal{W} >= \exp\left[-\frac{GM^2}{2\hbar c}\sum_l (|\alpha_l|^2 \coth\frac{\hbar\omega_l}{2k_BT})\right]$$

Has gravity, quantum, relativity and statistical mechanics in it

Decoherence sets in when M is around
Planck Mass exactly as Feynman anticipated

THANK YOU