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Decoherence, Scalar Fields and Quantum Gravity

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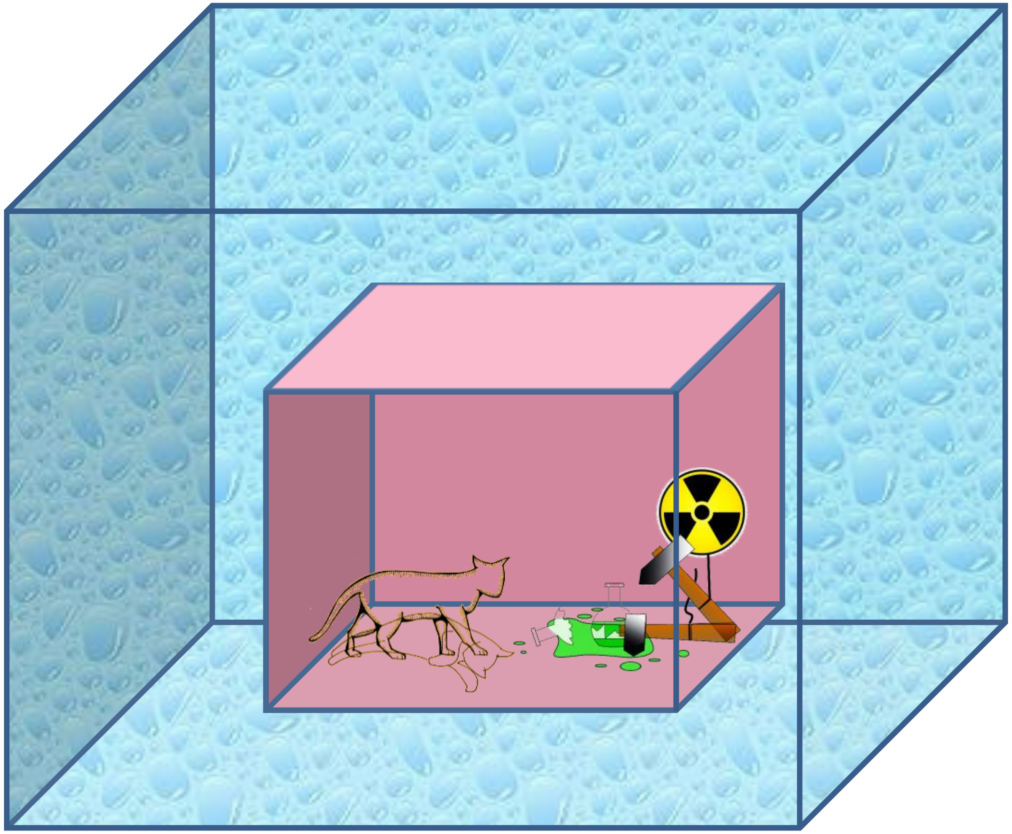
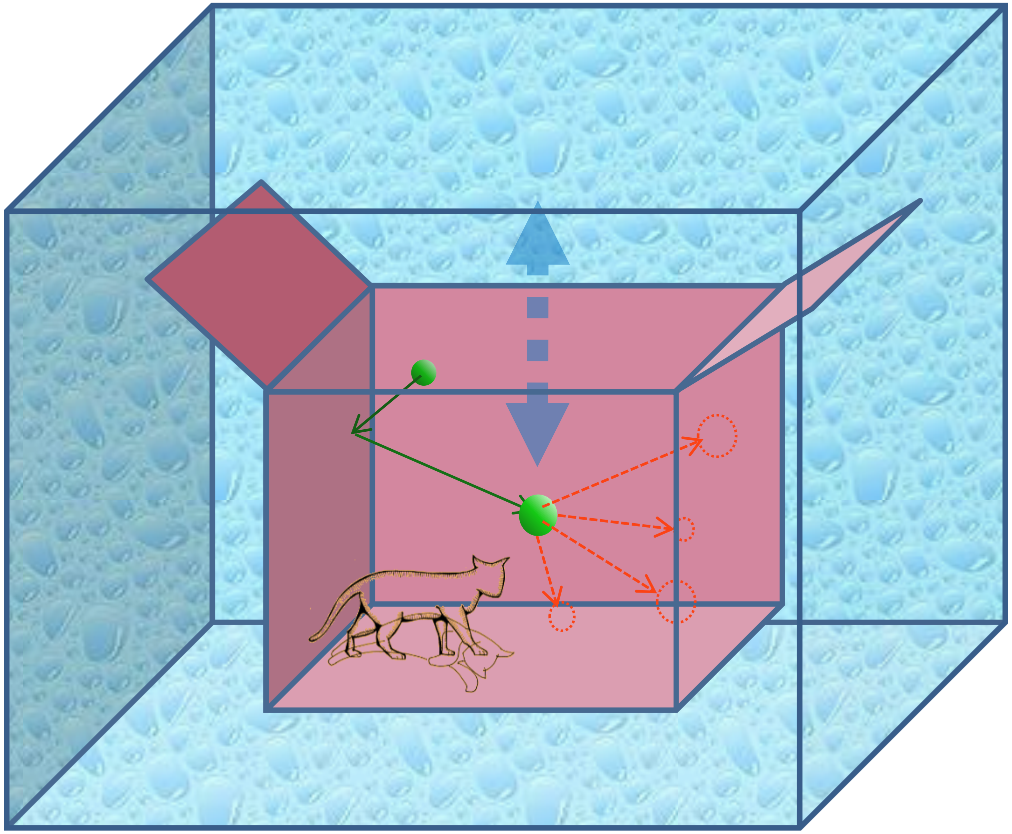
The Schrödinger cat paradox

[Schrödinger 1935]



Quantum mechanics would predict a creature inside a closed box to be alive and dead at the same time with a superposition state!

Open quantum systems:
Real-world Schrödinger’s cat?



In addition to quantum superposition illustrated here with Schrödinger’s cat, particles in a box open to fluctuations develop into a statistical mixture of states through entanglement with environmental fields.

Gravitational decoherence

- Quantum nonlocality expressed in the Bell inequality, which has been verified to high accuracies [Handsteiner et al, PRL (2017)].
- Quantum decoherence provides a dynamical mechanism of quantum-to-classical transition.
- Penrose's gravitational decoherence relates uncertain time measurement from superposition states to instability leading to the collapse of the wavefunction [Penrose (1996)].
- Can an unprecedented macroscopic quantum superpositions achieved by AION provide a test of Penrose's gravitational decoherence.

Quantum gravitational decoherence

- A decoherence model due to the quantum fluctuations of spacetime was given by [1] with quantum gravitational decoherence of a general quantum system formulated in [2, 3].
- This theory can be extended to include scalar gravitons, dilatons, and pseudo-scalar bosons such axions.
- The results may be employed in the visibility analyse of the singles from the AION interferometers to infer the existence of tensor and scalar gravitons as evidence of low energy quantum gravity and other incoherent scalar and pseudo scalar bosons as evidence of ultralight dark matter that may vary stochastically.

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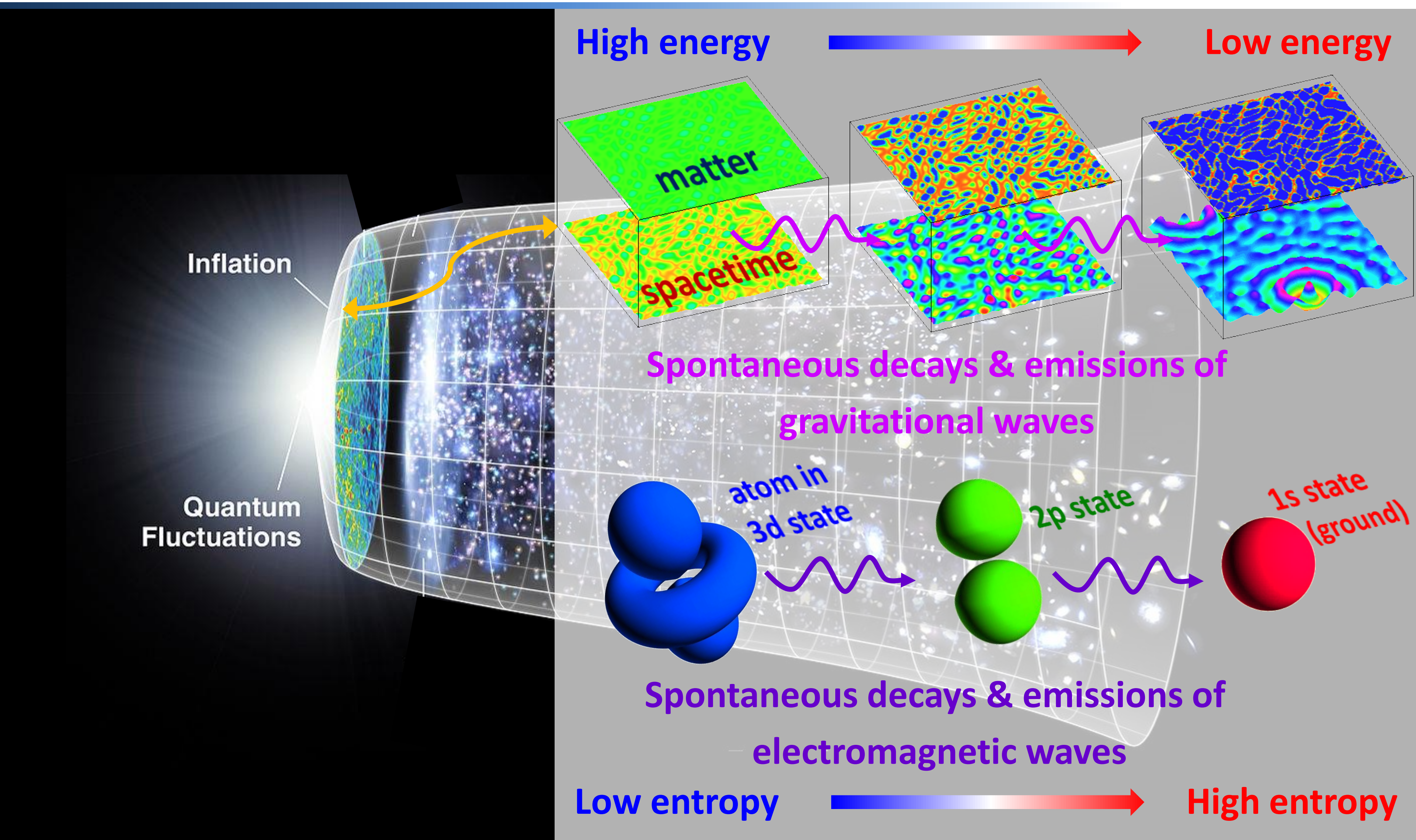
1. C. H.-T. Wang, R. Bingham, J. T. Mendonca, Quantum gravitational decoherence of matter waves Class. Quantum Grav. **23**, L59 (2006)
2. T. Oniga, C. H.-T. Wang, Quantum gravitational decoherence of light and matter, Phys. Rev. D **93**, 044027 (2016)
3. T. Oniga, C. H.-T. Wang, Quantum coherence, radiance, and resistance of gravitational systems, Phys. Rev. D **96**, 084014 (2017)

Cosmic structure formation via quantum-to-classical transition



Stochastic gravitational waves from the early Universe & quantum gravity

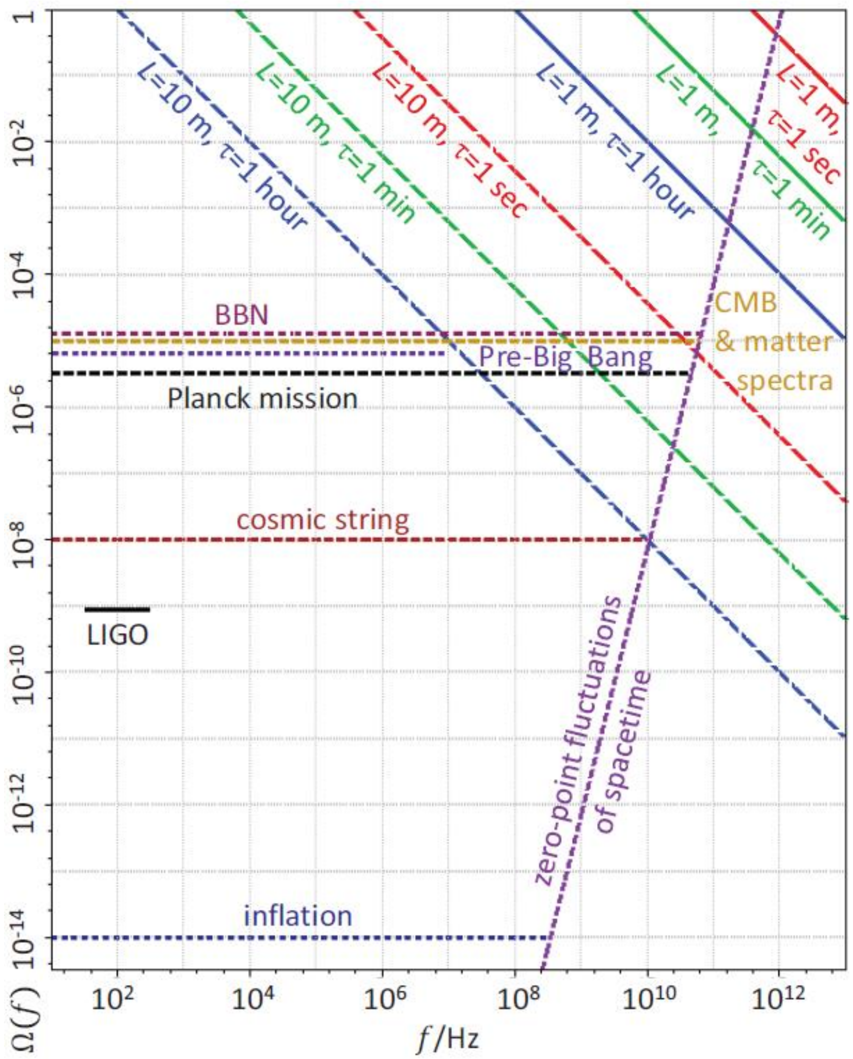


FIG. 1. Theoretical lower bounds for the spectral functions of stochastic gravitational waves $\Omega(f)$ determined by Eq. (66) that could be detected using an ensemble of correlated two-level atoms contained in an off-resonant high-Q cavity of volume L^3 and measurement time τ. Specifically, we consider heliumlike atoms with atomic quantum numbers $n_1 = n_2 = 2$, $l_1 = l_2 = 1$ and $-m_1 = m_2 = 1$, with a transition frequency induced by a Zeeman-type shift. For conventional stochastic gravitational waves, we have $\Omega(f) = \Omega_{\rm gw}(f)$ with $\tau = \tau_{\rm gw}$, whereas for zero-point, i.e. vacuum, metric fluctuations, we have $\Omega(f) = \Omega_{\rm vac}(f)$ with $\tau = \tau_{\rm vac}$ introduced in this work by Eqs. (62) and (64). In both cases, we choose $\tau = 1$ sec, min, and h as possible (future) transition times for the atoms with $L = 1$ and 10 m in generating the above diagram. It suggests, for example, measuring the zero-point fluctuations of spacetime would require a 1 m^3 cavity with a measurement time of 1 sec at $f = 1$ THz approximately. Note that regions where the values of $\Omega_{\rm gw}(f)$ are below that of $\Omega_{\rm vac}(f)$ would present a less stochastic gravitational wave signal to vacuum fluctuations "noise" ratio and hence the detection of the latter would be more likely using the discussed quantum methods. For comparison, we have superimposed the expected spectral functions of stochastic gravitational waves from various sources such as inflation, up to frequencies dominated by spacetime fluctuations, that may be detected by different methods such as LIGO from Ref. [21] and its references.

[Quinones, Oniga, Varcoe, Wang, Phys. Rev. D 96, 044018 (2017)]

Scalar fields in Dark Matter and Quantum Gravity

- Background independent quantization of gravity free from a fundamental scaling ambiguity generally necessitate a set of dilaton scalar fields [1].

- The resulting scale-invariant universe may provide a natural resolution to the hierarchy problem in particle physics and inflation in cosmology [2].

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1. C. H.-T. Wang, D. P. F. Rodrigues, Closing the gaps in quantum space and time: Conformally augmented gauge structure of gravitation, Phys. Rev. D **98**, 124041 (2018).

2. P. G. Ferreira, C. T. Hill, J. Noller, and G. G. Ross, Inflation in a scale invariant universe, Phys. Rev. D **97**, 123516 (2018).

The End – Thank you!