Searching for neutrino decoherence from quantum gravitational space-time fluctuations with IceCube

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for the IceCube collaboration

CARLSBERG FOUNDATION
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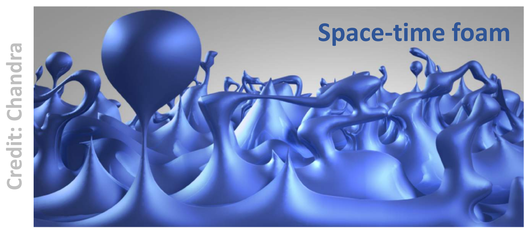
IceCube

1. Neutrino decoherence from quantum gravity

If gravity is a quantum force, the curvature of space-time may fluctuate at extremely small distance scales → **space-time foam**.

Sufficiently strong fluctuations conjectured to produce short-lived **virtual black holes** (VBH).

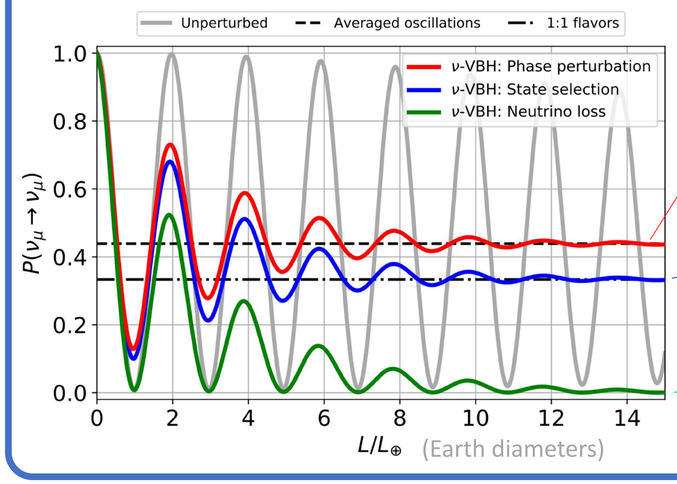
Stochastic interactions of neutrinos with VBHs can produce **loss of coherence** and other observable effects.



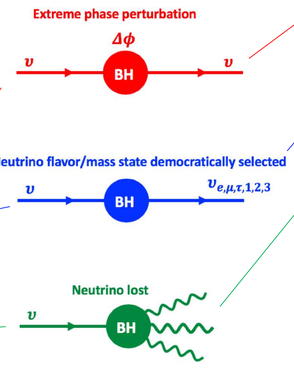
2. Modelling ν-VBH interactions

Model by stochastically **injecting heuristic ν-VBH interaction** scenarios into neutrino propagation software model.

Effect on neutrino ensemble is **damping of oscillations.**



3 scenarios tested:



Can reproduce signal analytically with open quantum system formalism:

$$\dot{\rho} = -i[H,\rho] - \mathcal{D}[\rho] \quad \Rightarrow \quad \mathcal{D}[\rho] = (D_{\mu\nu}\rho^{\nu})b^{\mu}$$

$$D_{\text{phase perturbation}} = \text{diag}\left(0\ \Gamma\ \Gamma\ \Gamma\ \Gamma\ \Gamma\ \Gamma\ \Gamma\ \Gamma\right)$$

$$D_{\text{state selected}} = \text{diag}\left(0\ \Gamma\ \Gamma\ 0\ \Gamma\ \Gamma\ \Gamma\ \Gamma\ 0\right)$$

$$D_{\text{neutrino lost}} = \text{diag}\left(\Gamma\ \Gamma\ \Gamma\ \Gamma\ \Gamma\ \Gamma\ \Gamma\ \Gamma\ \Gamma\right)$$

Allows interpretation of model limits in terms of underlying ν-VBH interaction parameters:

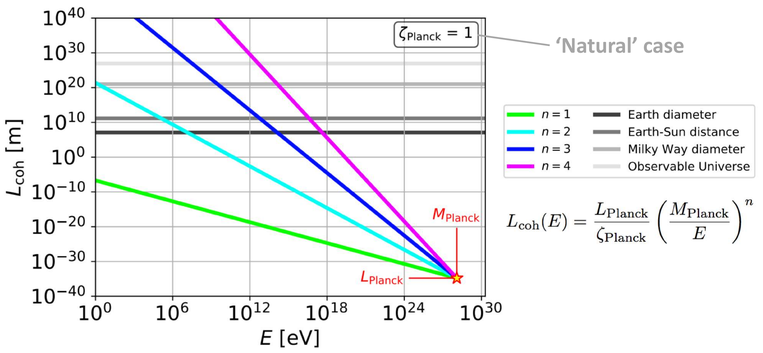
→ $\mathbf{1/\Gamma}$ **= interaction mean free path.**

Coherence length: $L_{\text{coh}} \equiv 1/\Gamma$ (= Earth diameter in example to left)

3. Energy dependence

No accepted quantum gravity theory → instead test a range of phenomenological ν-VBH interaction energy-dependence cases.

Express relative to Planck scale physics: $\Gamma(E) = \zeta_{\text{Planck}} \dfrac{E^n}{M_{\text{Planck}}^{n-1}}$



$$L_{\text{coh}}(E) = \frac{L_{\text{Planck}}}{\zeta_{\text{Planck}}}\left(\frac{M_{\text{Planck}}}{E}\right)^n$$

Sensitivity to 'natural' Planck scale physics for n<3 with atmospheric ν

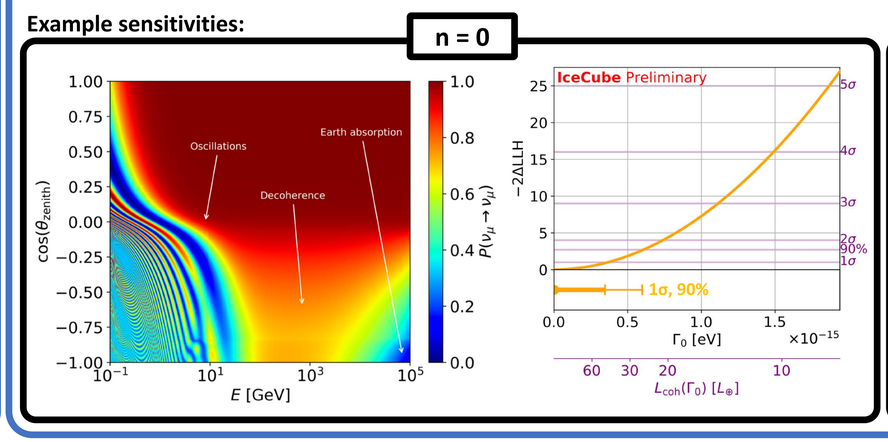
4. A search with DeepCore

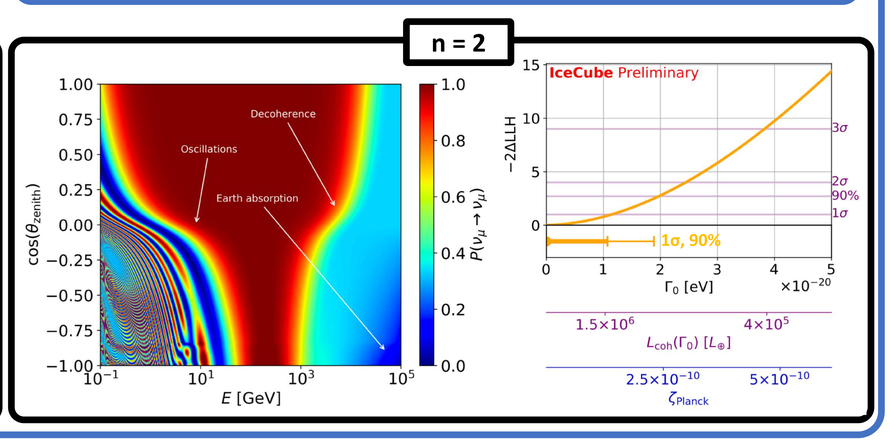
DeepCore is the dense core of the IceCube neutrino observatory.

Performing an experimental search for modified atmospheric ν oscillations consistent with ν-VBH interactions.

Using new 8 year 5-300 GeV data sample (>300,000 ν) → results soon!

Example sensitivities:





References

[1] G. Lindblad, Comm. Math. Phys. 48, 119 (1976)
[2] E. Lisi, A. Marrone, and D. Montanino, Phys. Rev. Lett. 85, 1166 (2000)
[3] F. Benatti and R. Floreanini, Journal of High Energy Physics, 032 (2000).
[4] A. M. Gago, E. M. Santos, W. J. C. Teves, and R. Z.Funchal, arXiv:hep-ph/0208166 (2002)

Coming soon...

1) Phenomenology paper (ν-VBH interactions, lightcone fluctuations)
2) DeepCore (GeV) and IceCube (TeV) experimental results

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