Max-Planck-Institut
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Holographic noise in ET

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Prehistory. Black hole thermodynamics

- Black holes radiate and have a finite temperature and associated entropy.
- Entropy of the black hole is proportional to the area of the event horizon

$$S = \frac{1}{4}\frac{A}{l_P^2},$$

not the volume inside the black hole. Here l_P is the Planck length.

Holographic principle

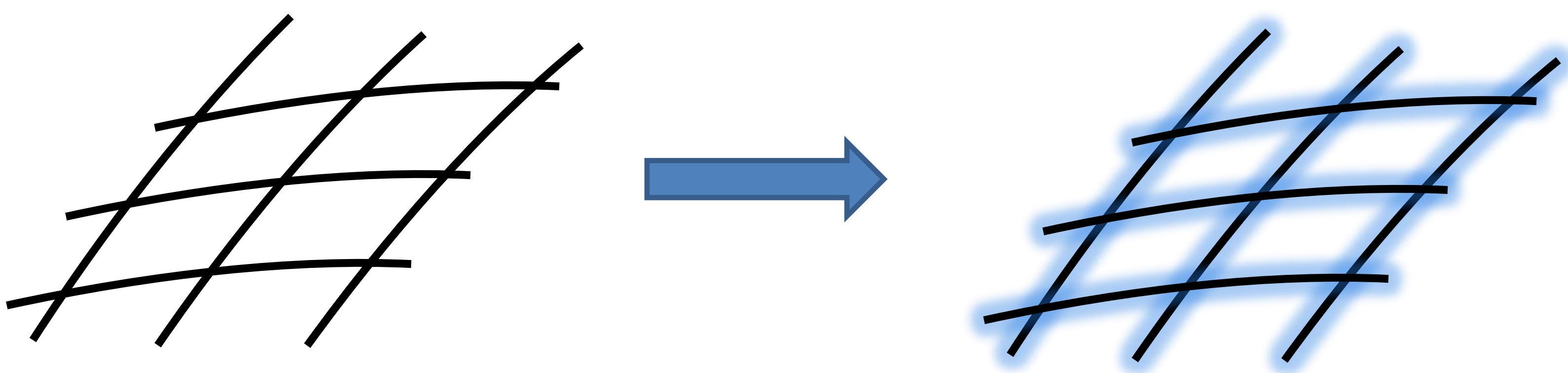
- Entropy and information are essentially the same, measured in different units. Both are descried by Boltzmann-Shannon formula $S = \log \Gamma$.
- All information about the black hole state is “encoded” on its event horizon. A bit of information per Planck square.
- Holographic principle (‘t Hooft, Susskind). Physics of any bounded region of space (even the whole Universe) is “encoded” on the bounding surface, preferably a light-like surface.

Holographic uncertainty

- “Classical” 3D description of the world contains much more degrees of freedom than allowed by the holographic entropy bound.
- 3D world must be “fuzzy” to match the number of degrees of freedom inscribed on the 2D surface.
- Holographic uncertainty (C. Hogan, 2007) is a particular hypothesis about how holography works in almost flat space-time.

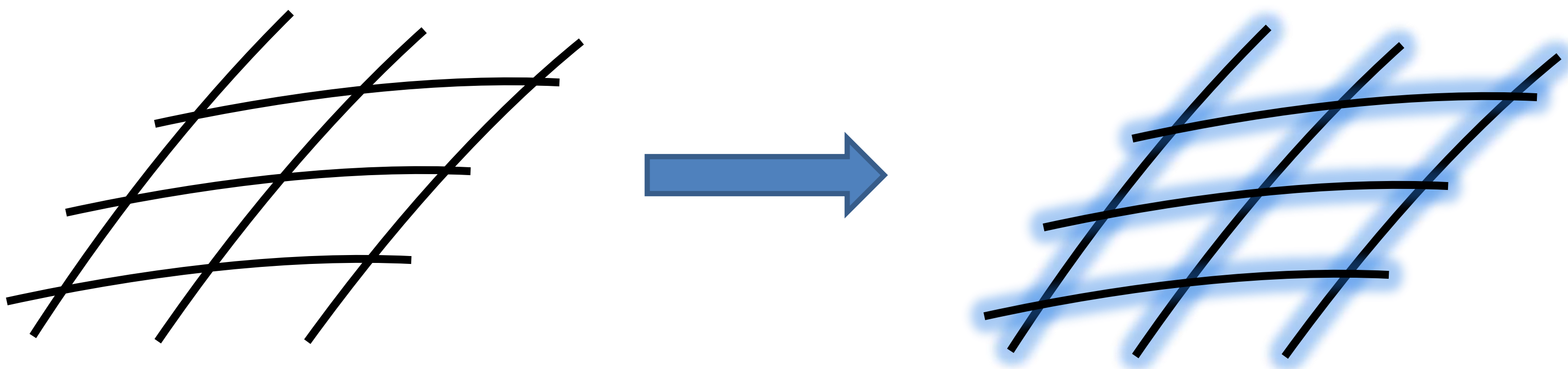
Holographic uncertainty

- Classical space-time can be defined by the waves in the geometric optics limit $\lambda = 0$.
- New assumption: space-time is defined with the Planck-length waves. Since $\lambda \neq 0$ transversal localization of the space-time events is limited by diffraction.

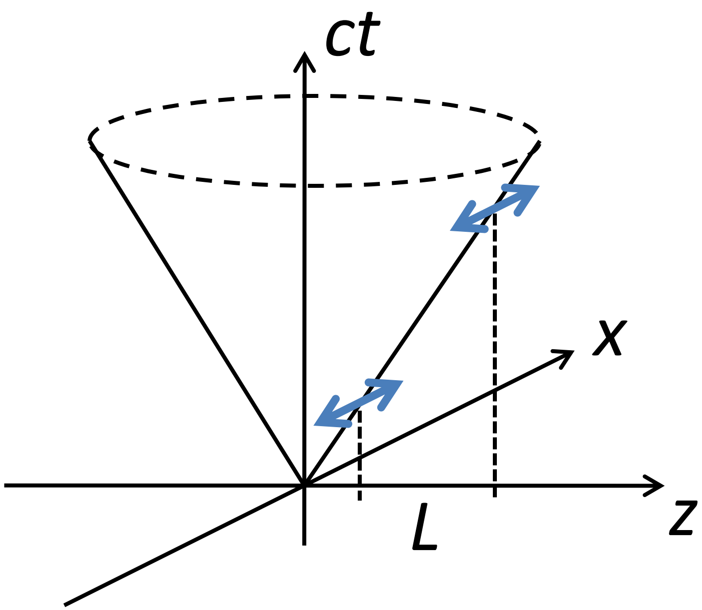


Holographic uncertainty

- Planck-scale waves are the quantum mechanical wavefunctions of mass-energy distribution in space-time.
- They are the solutions of effective parabolic equation in Matrix theory.



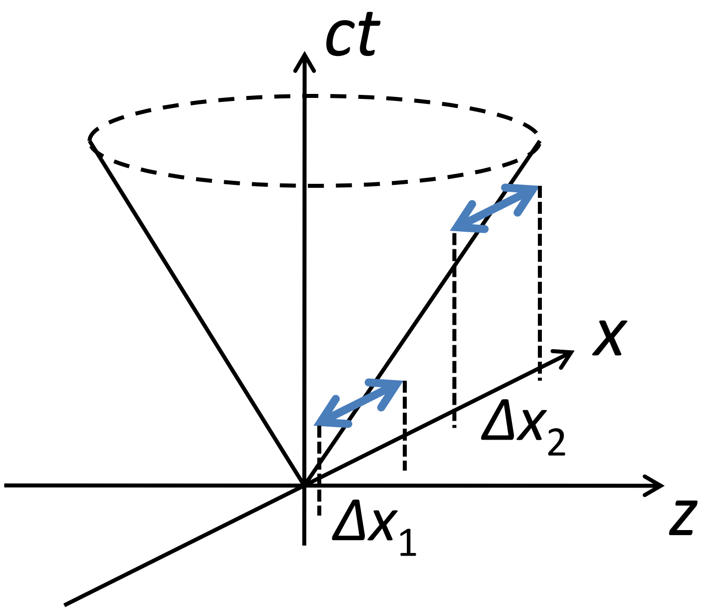
Holographic uncertainty



- *Z* is the longitudinal direction.
- *X* is one of the transversal directions.
- Two test masses (or two measurement events) are separated by a spatial *Z* and/or temporal direction

- Holographic nature of space-time manifests itself through new commutator: transversal positions of the test masses no longer commute $[x_1,x_2] = i l_P L$.

Holographic uncertainty



- Holographic commutator reveals non-local correlations in space-time which respect holographic principle.
- Commutation relation leads to the uncertainty principle: $\Delta x_1 \Delta x_2 \geq l_P L$

- If we measure the position of a single test mass with the optical signals then holographic uncertainty dictates that $\Delta x \geq (l_P L)^{1/2}$.

Holographic noise in interferometers

- Holographic fuzziness can be seen in precise interferometry, otherwise it would be possible to distinguish more test masses configurations than allowed by the holographic entropy bound.
- Holographic uncertainty implies that the relative transversal positions of the test masses cannot be measured better than $\Delta x = C(l_P L)^{1/2}$. Numerical coefficient *C* depends on space-time wavefunctions which describe test masses transversal positions.

Holonoise in Michelson interferometer

- In a Michelson interferometer holographic noise should appear as a white noise (up to FSR) of beamsplitter motion with effective metric strain $h \approx t_P^{1/2} \approx 10^{-22}\ \mathrm{Hz}^{-1/2}$. Measurement events are two reflections at the beamsplitter (splitting and recombination of the laser beam).
- Possibly already observed in GEO-600. However, prediction for the holographic noise still lies within the error bar.

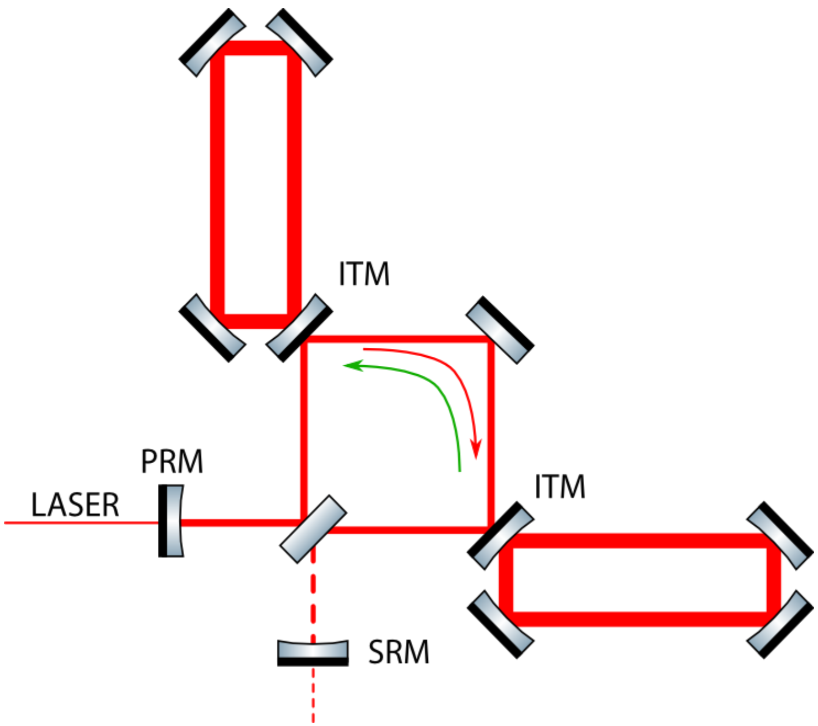
Holonoise in ET. Xylophone

- Effective metric strain in a single Michelson/Fabry-Perot interferometer is $h \approx (1/N) t_P^{1/2} \approx (1/N) 10^{-22}\ \mathrm{Hz}^{-1/2}$, where N is an effective number of reflections inside the arm cavities.
- For two Michelson/FP interferometers separated by ΔL holographic noise should exhibit cross-correlation with spectral density

$$S_h = \frac{t_P}{N^2}\left(1 - \frac{\Delta L}{L}\right), \quad f \ll c/L$$

Holonoise in ET. Sagnac

- According to C. Hogan, holographic spreading depends only on the real spatial scale of the device, therefore effective metric strain should be $h \approx (1/N)t_P^{1/2} \approx (1/N)10^{-22}\ \mathrm{Hz}^{-1/2}$.



- However, unlike the linear Michelson/FP layout, Sagnac topology exhibits multiple transversal reflections. Requires further study.

Conclusions

- Although strongly motivated from theoretical side, holonoise hypothesis remains completely unexplored from experimental one. Several experiments are underway: GEO-600, table-top experiment in Hannover, holometer in Fermilab…
- Complex interferometer configurations require detailed theoretical analysis.
- Holonoise might be a dangerous noise source for the GW detectors. From the other side, if proven to exist, it will be even more fundamental than the GW discovery itself.