# Quantum Metrology for Space-Based Tests of Gravitational Physics

## Energy-Entangled photon pairs for probing general relativity with quantum states

## Executive Summary

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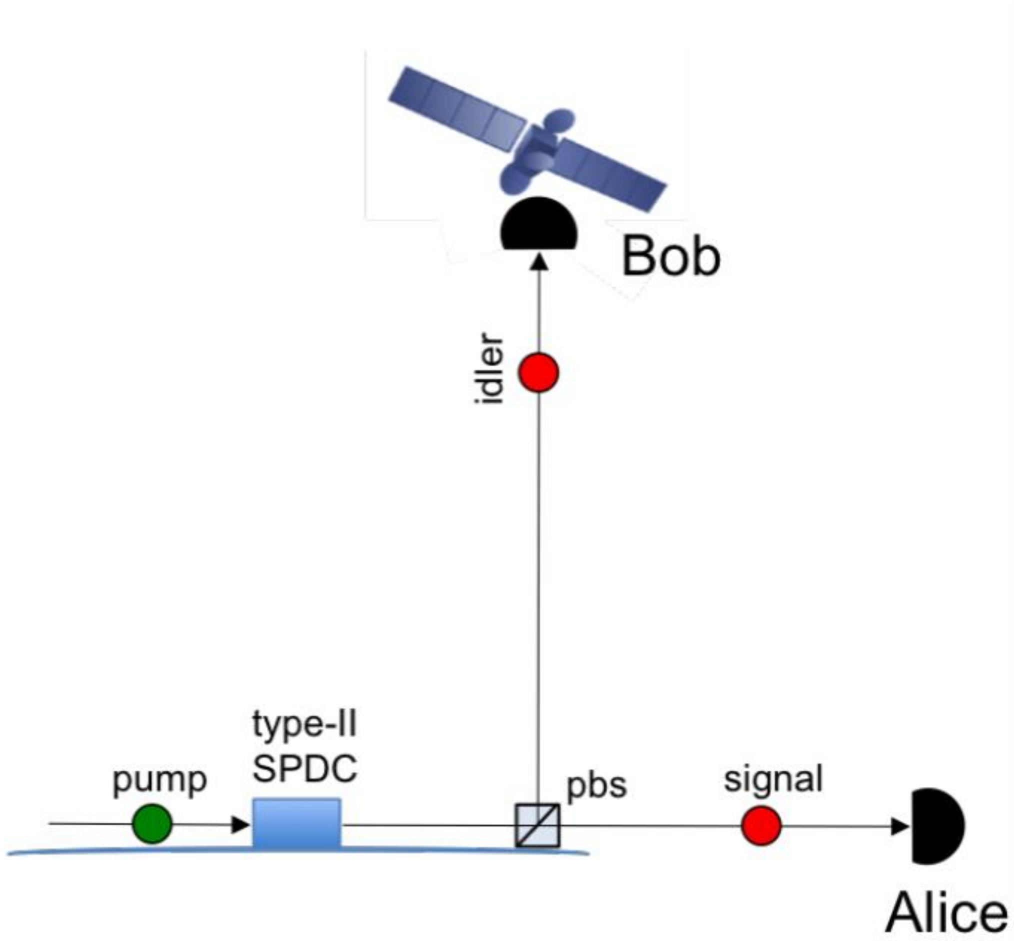
**Picture:**




**Motivation:**
This study aimed to develop a framework for studying the effects of spacetime curvature on the propagation of quantum states of light, and to compare them with the propagation of classical light.

**Methodology:**
When distributing entangled photon pairs through a gravitational potential, the effect of spacetime curvature on the properties of quantum states can become significant. This could be relevant for plans to use satellites for global quantum key distribution. From the fundamental point of view, situations where both quantum and relativistic effects are relevant, are expected to give physical insights.

Our methodology is to develop a general formalism, building on quantum field theory in curved spacetime, that describes the physical process of wave-packet propagation on a curved background. We then evaluate the predicted first and second order correlation function for single photon state and entangled photon pairs respectively. We then evaluate the effects of the curvature on the interference seen by a Franson type experiment where the two interferometers are located at different positions in the gravitational potential. This will be compared against the sensitivity of experiments that are limited by single photon counting.

**Results:**

- Within the QFTCS framework, the propagation of quantum states of light can be non-ambiguously described, once a specific frame is chosen.
- The apparent change of quantum states when distributed from one frame to the other, is fundamentally not different from the classical red shift.
- The visibility of two photon interference in a Franson scheme, as a witness of entanglement, is not affected by the curvature.
- Red shift effects being small, a statistically large number of detection events is needed, when observed with single photons. It is limited by the single photon counter saturation rate. We show that multiplexing 1000 such detectors, a count rate of 1 GHz could be achieved.

**Publications:**

- No publications to date.

**Highlights:**

In the absence of a unified theory, QFTCS seems to be the most adequate way to describe relativistic effects on quantum states of light. The propagation of quantum states as predicted by QFTCS do not differ fundamentally from the propagation of classical light. However, because of the curvature, the choice of reference frame in which the experiment has to be described is critical and should match the actual experimental configuration in order to correctly interpret the predictions.