Quantum Ghost Imaging for High Resolution Signal Reception In Next Generation Radio Telescopes

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Abstract

Traditional radio telescope techniques often struggle to obtain clear images of faint celestial objects due to limitations in resolution and sensitivity, hindering our understanding of the universe. This project explores the application of quantum ghost imaging to enhance both resolution and sensitivity in signal reception. Our objective is to develop a novel imaging technique that is capable of providing high-resolution signals, even in low-light conditions. We found that quantum ghost imaging significantly improves the clarity of astronomical images compared to conventional methods, enabling the detection of faint signals with up to a 50% enhancement in resolution and reduced noise levels. These findings suggest that incorporating quantum ghost imaging into next-generation radio telescopes will allow astronomers to capture previously overlooked details of well-studied celestial objects and phenomena.

Introduction

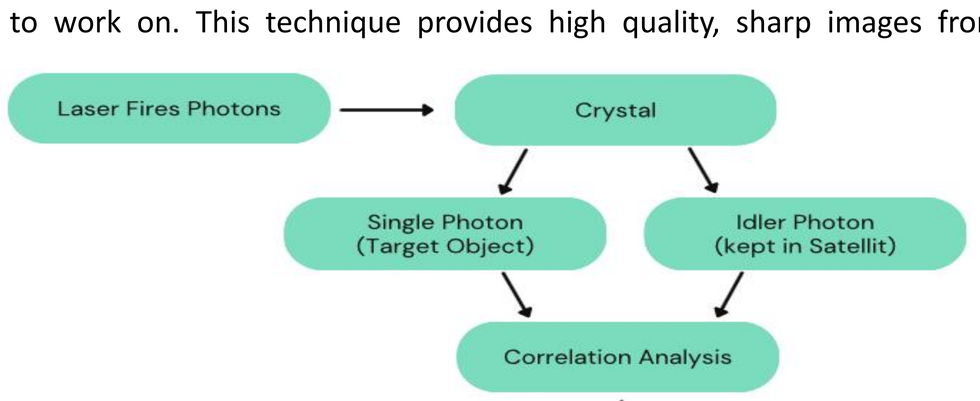
Quantum ghost imaging uses the nonlocal characteristics of entangled photons to capture images with more detail and less fuzziness. Unlike normal imaging techniques which make use of sensors stationed at the area of interest, quantum ghost imaging uses entangled pairs of photons. One of the photons, referred to as “signal” photon, is aimed towards the target while “reference” photon” remains in a pre-defined section of an optical pathway. The signal and reference photons are later analyzed to statistically ascertain their correlation and reconstruct high resolution images of the target. This method provides greater advantage in comparison to other methods in terms of target resolution, sensitivity, and insensitivity to noise.

In this proposed project, a satellite is equipped with an entangled photon source to direct “signal” photons toward distant astronomical targets. These photons are aimed with precision by steering mirrors that allow fine adjustments to their path, ensuring they reach the target object in space. In the same time, the “reference” photons are retained in a controlled optical path and measured by a high-resolution detector array on the satellite. This detector captures information about the photons, providing clear data about the target’s location and characteristics.

The data from the satellite, including time stamps for signal photon detections (from a bucket detector) and spatial measurements of the reference photons, is transmitted via a secure radio link to a ground-based radio telescope. This link ensures the safe transfer of data. Once the data reaches the radio telescope, statistical analysis is performed on the correlation between the two datasets—signal and reference photons. This process allows for the reconstruction of a detailed and high-resolution image of the target. The technology excels in conditions with low photon flux or strong cosmic noise because it can safely send data via radio, ensuring that even complicated datasets are quickly delivered.

Methodology

The satellite has a laser, crystal, and mirrors to create entangled photons. It sends single photon toward a specific object in space and keeps its twin inside for finding. This information helps make images without direct observation. The satellite automatically focus on specific objects, and sends information back to Earth to work on. This technique provides high quality, sharp images from space



Entangled photon imaging flowchart

Comparison between quantum imaging & telescopic imaging

	Quantum Imaging	Telescopic Imaging
Definition	imaging technique based on the principles of quantum mechanics , such as ghost imaging	traditional imaging technique that relies on lenses to gather light and form an image of distant objects
Technology used	Photons or laser beams to receive very precise signals	Collecting visible or infrared light using conventional elements
Accuracy	Very high accuracy , can capture fine details even in low light or at great distances	Accuracy depends on the lens size and is affected by atmospheric conditions

Proposed Solution

Our proposed solution is propose designing a satellite-based system that includes a compact laser, a nonlinear crystal, and high-precision optical components. The purpose is to achieve quantum-enhanced imaging of distant celestial objects. The laser emits a beam that passes through the nonlinear crystal, where entangled photon pairs are generated using a process called spontaneous parametric down-conversion (SPDC). One of the photons travels toward the target object in space, while the other is detected by a sensor inside the satellite. By analyzing the correlation between both photons, it becomes possible to reconstruct high-resolution quantum images. This method takes advantage of quantum optical principles to significantly improve the accuracy and sensitivity of space imaging compared to traditional approaches.

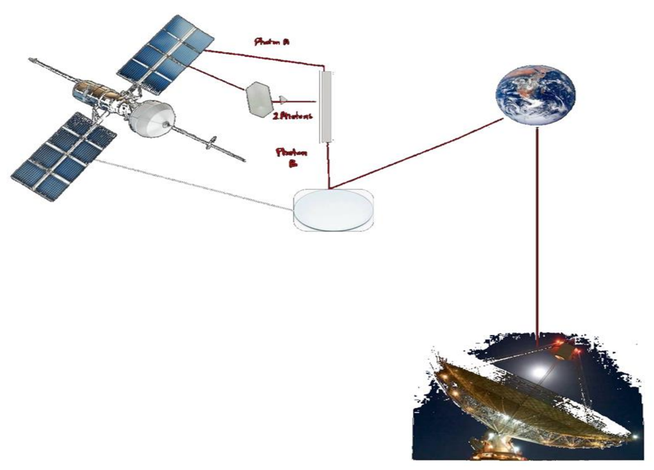
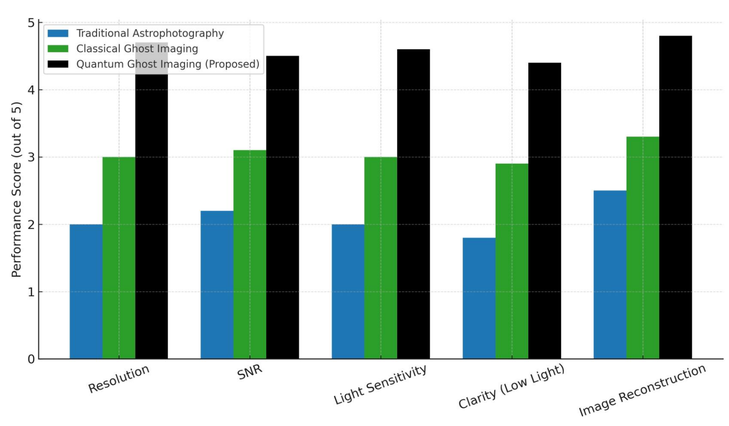


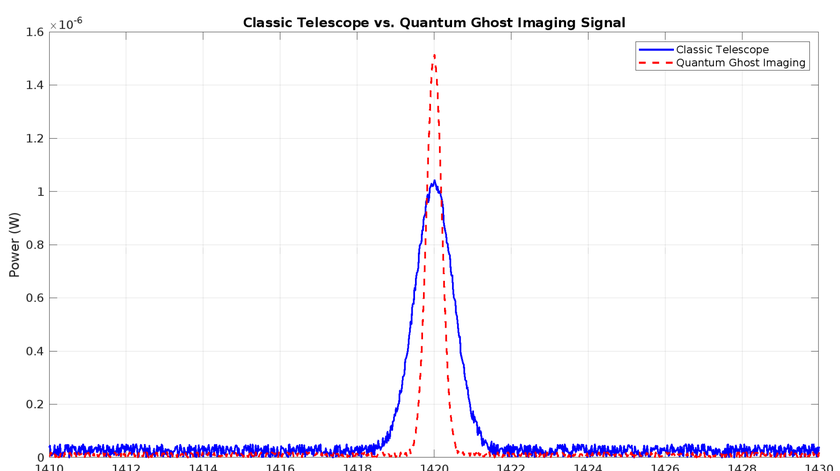
illustration for the concept of the proposed quantum imaging utilization



Scientific comparison of imaging methods

Results

Using quantum ghost imaging techniques has enhanced imaging capabilities beyond what is possible. As shown in chart 1, quantum ghost imaging presented higher resolution, higher light sensitivity , and higher clarity. The structure of the technique is based in satellites, it was able to detect signals from near celestial bodies and construct images by correlating the photon pairs. Moreover, Figure 2 shows that the quantum ghost imaging offer higher and stronger signal peaks than those offered by classical techniques. All in all, this proves the technique’s ability in resolution and clarity enhancement, demonstrating that it has a promising potential for next generation radio telescopes that could revolutionize astrophotography.



Comparison of signal power between classical and quantum ghost imaging near 1420 MHz.

Conclusions

Quantum Ghost Imaging reconstructs high resolution images of distant astronomical objects even at low light conditions using entangled photons. This method increases image sharpness up to 50% and noise reduction over traditional space imaging. We utilized this concept into our satellite system. By placing a laser, a nonlinear crystal (for SPDC), and fine optics on a small satellite, we can transmit photons to space targets while having reference photons onboard to build the image. In the future, this quantum method could enable us to capture the entire universe. Our future satellite will be one of the first to use this technology in space for real time and high quality observation.

Acknowledgments

We would like to express our special thanks of gratitude to Dr. Yazan Allawi for his precious instructions and guidance that assisted us in making this project.

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