Robust photon-pair source survives rocket explosion

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A sensitive quantum device, designed to operate on a nanosatellite, was recovered from explosion debris and displays no degradation in quality.

Quantum key distribution (QKD), i.e., using quantum signals to generate secure symmetric key material at distant sites, is of much interest for quantum communications because of its high level of privacy (underpinned by quantum mechanics). In particular, entanglement-based QKD\textsuperscript{1} is a powerful technique in which quantum correlations between photons are leveraged. In this process, the entangled photons can be distributed with the use of optical fibers or ground-level free-space links. Current QKD networks, however, suffer from a distance limit because of fiber losses\textsuperscript{2,3} and the lack of quantum repeaters.\textsuperscript{4}

There are several ongoing efforts to overcome this distance limit and to produce regional/global QKD networks.\textsuperscript{5-10} In these approaches, a source of entangled photons, on board a satellite, would be used to beam the photons down to widely separated receivers. A major milestone in achieving this endeavor would therefore be the successful demonstration of an entangled-photon pair source in low Earth orbit (LEO). It has previously been proposed that CubeSat nanosatellites are a cost-effective way to realize this aim (because technology validation experiments can be performed in small, iterative steps).\textsuperscript{11} However, spontaneous parametric downconversion\textsuperscript{12}—the ‘workhorse’ method for generating entangled-photon pairs—requires the use of precisely aligned bulk optics. This means that it can be challenging to design a photon source that has sufficiently low size, weight, and power requirements to be used on a nanosatellite.

We have thus been working on the development of a compact device that is designed to perform pathfinder experiments in the pursuit of achieving global quantum communication networks. In particular, our device is designed to generate and measure photon pairs in space. In the first step toward validation in a space environment, we assembled a science package that comprised a correlated photon-pair source (with one spontaneous parametric downconversion crystal) and the necessary electronics. The complete package, i.e., the optical source\textsuperscript{13} and electronic control systems,\textsuperscript{14} had a form factor of 9.5 × 9.6 × 3.8cm, and a mass of 250g.

In our design, the optical components (crystals and mirrors) are both located within a recessed pocket (which is machined into the aluminum housing). In addition, we designed the optical unit with rails so that we could slide a customized adjuster into the correct position before securing it with a clamp (see

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Figure 2). With our customized adjustor, we can provide adjustments along both the x- and y-axes (yaw and pitch, respectively). We also inject epoxy into the pocket to secure the optical components and remove the adjuster once it has cured. We have previously reported the successful space qualification testing for the complete device (in which the device survived a helium balloon ride into near-space).\textsuperscript{15}

In the next stage of our validation experiments, we installed our device on the GomX-2 nanosatellite (see Figure 1), which was to be deployed in LEO on the International Space Station. On 28 October 2014, an unmanned Antares supply rocket with GomX-2 on board was launched from Virginia. Unfortunately, however, a failure occurred and the rocket was destroyed 15 seconds after liftoff. Although GomX-2 never reached space, the satellite was later retrieved from the rocket’s debris and was, surprisingly, found to be completely operational.

Upon recovery of GomX-2, we operated our device to investigate the post-explosion correlation quality of the photon source. By electronically tuning the polarization rotators within the device, the rate of coincidence counts can be made to exhibit a sinusoidal variation. The polarization contrast (visibility) can thus be used to quantify the source’s quality of the correlation. Our plot of the visibility before and after the explosion (see Figure 3) shows that there was no degradation in the device’s performance.\textsuperscript{13, 16} The Antares launch failure also highlighted an important advantage in using nanosatellites as test platforms. That is, the short design cycle and relatively low cost of nanosatellites meant that we could recover quickly from the failure. Indeed, in December 2015, a similar photon source was successfully launched into an equatorial Earth orbit, on board another CubeSat. Our early data from this device shows that the source is continuing to produce photon pairs in space, with high quality correlation.\textsuperscript{17}

In summary, we have presented results that illustrate the first 'bombproof' quantum light source. As part of an effort to realize a source of entangled photons on a satellite (for quantum key distribution purposes), we have designed a photon source for the generation and measurement of photon pairs within a space environment. Although a rocket carrying our device exploded soon after launch, we have found that the recovered source exhibits no degradation in quality. Our results thus indicate that sensitive quantum devices that are usually confined to controlled laboratory environments can be engineered to withstand extreme conditions. We are currently testing a new mounting technique for the crystals in our device, and we are upgrading our source to deliver entangled photon pairs. We hope to have the improved source ready next year to be used on board a dedicated nanosatellite, which we are calling ‘SpooQy-Sat.’

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Zhongkan Tang is currently pursuing his PhD. His research interests include nonlinear optics, designing entangled photon experiments on low-resource mobile platforms, and satellite instrument development.

References

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