Supplemental Document

Optics EXPRESS

Snapshot hyperspectral imaging with quantum correlated photons: supplement

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Supplement DOI: https://doi.org/10.6084/m9.figshare.21766589

Parent Article DOI: https://doi.org/10.1364/OE.462587

Supplemental document accompanying submission to *Optics Express*

Title: Snapshot hyperspectral imaging with quantum correlated photons

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Submitted: 4/27/2022 12:44:41 PM

Snapshot hyperspectral imaging with quantum correlated photons - supplemetary information

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Background subtraction

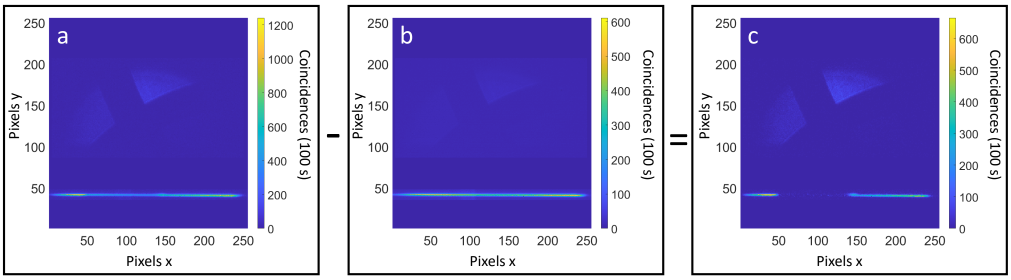

Fig. 1. Background subtracted coincidence image (c) is obtained by subtracting the background coincidence image (b), determined from eq. (2) of the main text, from the raw coincidence image (a).

Background subtraction in the coincidence image is demonstrated in Fig. 1. Between each pixel n of the idler beam and pixel m of the signal beam, the true coincidences between entangled photon pairs $C^{\text{true}}_{n,m}$ is the total measured coincidences $C^{\text{tot}}_{m,n}$ subtracted by the background/accidental coincidences $C^{\text{acc}}_{m,n}$ (which can be calculated according to eq. (1) of the main text)

$$C^{\text{true}}_{m,n} = C^{\text{tot}}_{m,n} - C^{\text{acc}}_{m,n}, \tag{1}$$

The raw coincidence image seen in Fig. 1(a) is a 2D projection of the 4D data given by $\sum_n C^{\text{tot}}_{m,n}$ for the signal image and $\sum_m C^{\text{tot}}_{m,n}$ for the idler spectrum, displayed on the same axes, i.e. $\sum_n C^{\text{tot}}_{m,n} + \sum_m C^{\text{tot}}_{m,n}$ (note that the pixel range of m and n does not overlap). Similarly, the background/accidental coincidence image, Fig. 1(b), is $\sum_n C^{\text{acc}}_{m,n} + \sum_m C^{\text{acc}}_{m,n}$. Thus, subtracting the two images gives

$$\left[\sum_n C^{\text{tot}}_{m,n} - \sum_n C^{\text{acc}}_{m,n}\right] + \left[\sum_m C^{\text{tot}}_{m,n} - \sum_m C^{\text{acc}}_{m,n}\right] = \sum_n C^{\text{true}}_{m,n} + \sum_m C^{\text{true}}_{m,n}, \tag{2}$$

which is the background subtracted coincidence image as seen in Fig. 1(c).

Spectrum correction

The steps to obtain the final signal photon spectrum, as discussed at the end of the “Experimental setup" section of the main text, is illustrated in Fig. 2.

To calculate the absorption spectrum of the target $S_{\text{targ}}(\lambda_s)$, we must account for the spectral response of the optics, and camera, and for the spectral profile of the SPDC photons. The

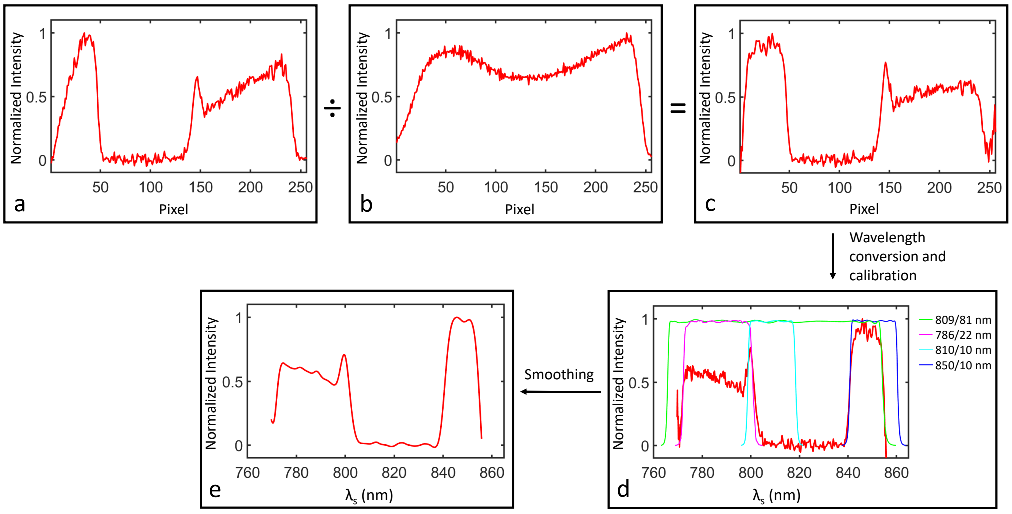

Fig. 2. The directly measured idler photon spectrum (b) is divided by the raw coincidence idler photon spectrum (a) to obtain a corrected coincidence spectrum of the idler photon (c). The pixel number is then converted to wavelength and inverted according to energy conservation, given by eq. (3) of the main text, to obtain the spectrum of the signal photon. The pixel to wavelength conversion is calibrated according to the edges of multiple spectral filters as seen in (d). The final spectrum (e) is obtained by smoothing (d) with a cubic spline fit in order to remove the large fluctuations seen on the edges of the spectrum, a result from division by small numbers during the correction from (a) to (c).

measured coincidence spectrum $S_{\text{coinc}}(\lambda_i, \lambda_s)$ in Fig. 2(a) is related to the spectral profile of each element as follows

$$S_{\text{coinc}}(\lambda_i, \lambda_s) = S_{\text{SPDC}}(\lambda_i, \lambda_s) \left[\eta_{\text{cam}}(\lambda_i)\eta_{\text{grat}}(\lambda_i)\right] \left[\eta_{\text{cam}}(\lambda_s)S_{\text{targ}}(\lambda_s)\right], \tag{3}$$

where η_{cam} and η_{grat} are the wavelength-dependent quantum efficiency of the camera, and grating efficiency respectively. We have ignored the spectral profile of simple optical elements such as lenses and mirrors which are mostly flat within the spectral region of this experiment. λ_s and λ_i are related through the conservation of energy as given by eq.(3) of the main text, i.e. $\frac{1}{\lambda_p} = \frac{1}{\lambda_s} + \frac{1}{\lambda_i}$. The measured idler photon spectrum as seen in Fig. 2(b) is given by the product of the SPDC spectrum with the camera and grating efficiencies:

$$S(\lambda_i) = S_{\text{SPDC}}(\lambda_i, \lambda_s) \left[\eta_{\text{cam}}(\lambda_i)\eta_{\text{grat}}(\lambda_i)\right]. \tag{4}$$

By dividing the coincidence spectrum by the idler spectrum as shown in Fig. 2, this returns an output spectrum Fig. 2(c) of the form:

$$S_{\text{out}}(\lambda_i) = \frac{\eta_{\text{cam}}(\lambda_s)S_{\text{targ}}(\lambda_s)}{\eta_{\text{cam}}(\lambda_i)\eta_{\text{grat}}(\lambda_i)}. \tag{5}$$

So we can see that this technique does not directly measure the spectrum of the target S_{targ} but rather, in common with all spectrometers, measures the product of the target spectrum and the instrument response. With careful intensity calibration of the camera system and measurements of the grating efficiency, S_{targ} could be determined, but this is beyond the scope of this work.

Conversion from position to wavelength in a spectrometer is slightly nonlinear, thus after inversion of the idler photon spectrum to obtain the spectrum of signal photon, a third order polynomial fit, given by $\lambda = ax^3 + bx^2 + cx + d$ (with λ the wavelength and x the pixel number), is made in order to match the obtained spectrum to the edges of the various spectral filters (with spectral response obtained from Semrock), this is seen in Fig. 2(d). Four points corresponding to the four filter edges at 772, 801, 841 and 854.5 nm were used to determine the four unknowns of the third order polynomial. The obtained parameters are $a = -4.83 \times 10^{-6}$ nm, $b = 1.78 \times 10^{-3}$ nm, $c = 0.199$ nm, $d = 770.5$ nm.