Tabletop Demonstration of Quantum-enhanced Interferometric Telescopy

David Diaz, Yujie Zhang, Yunkai Wang, Virginia Lorenz, Paul Kwiat

Department of Physics and Illinois Quantum Information Science & Technology Center, University of Illinois Urbana-Champaign

Abstract

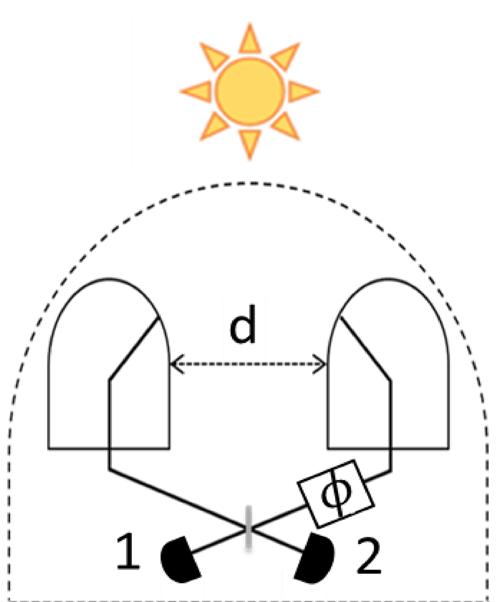
- We demonstrate the underlying mechanism for one version of quantum-enhanced telescopy
- The "astronomical" and "terrestrial" source couple into three interconnected Hong-Ou-Mandel interferometers
- Amplitude of the complex visibility of the "astronomical" source is recovered in the presence of turbulence
- Inducing two phase shifts onto our "terrestrial" photon is sufficient to recover the visibility amplitude.

Background

Interferometric telescopy can simulate one massive telescope using an array of smaller receivers.

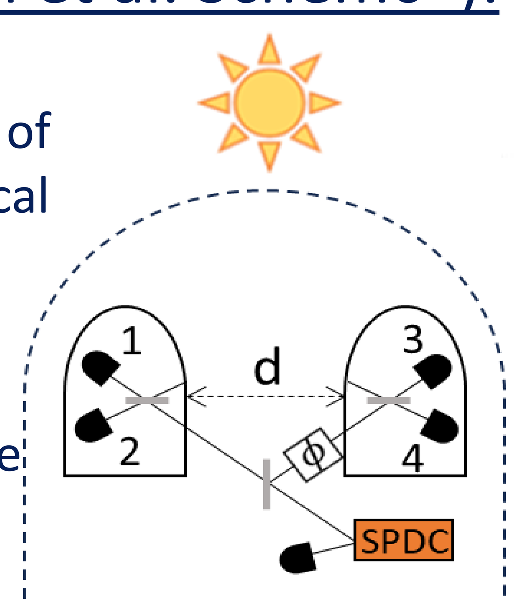
Classical:

- Dependent on the brightness of the astronomical source
- Direct-detection interference is limited by loss

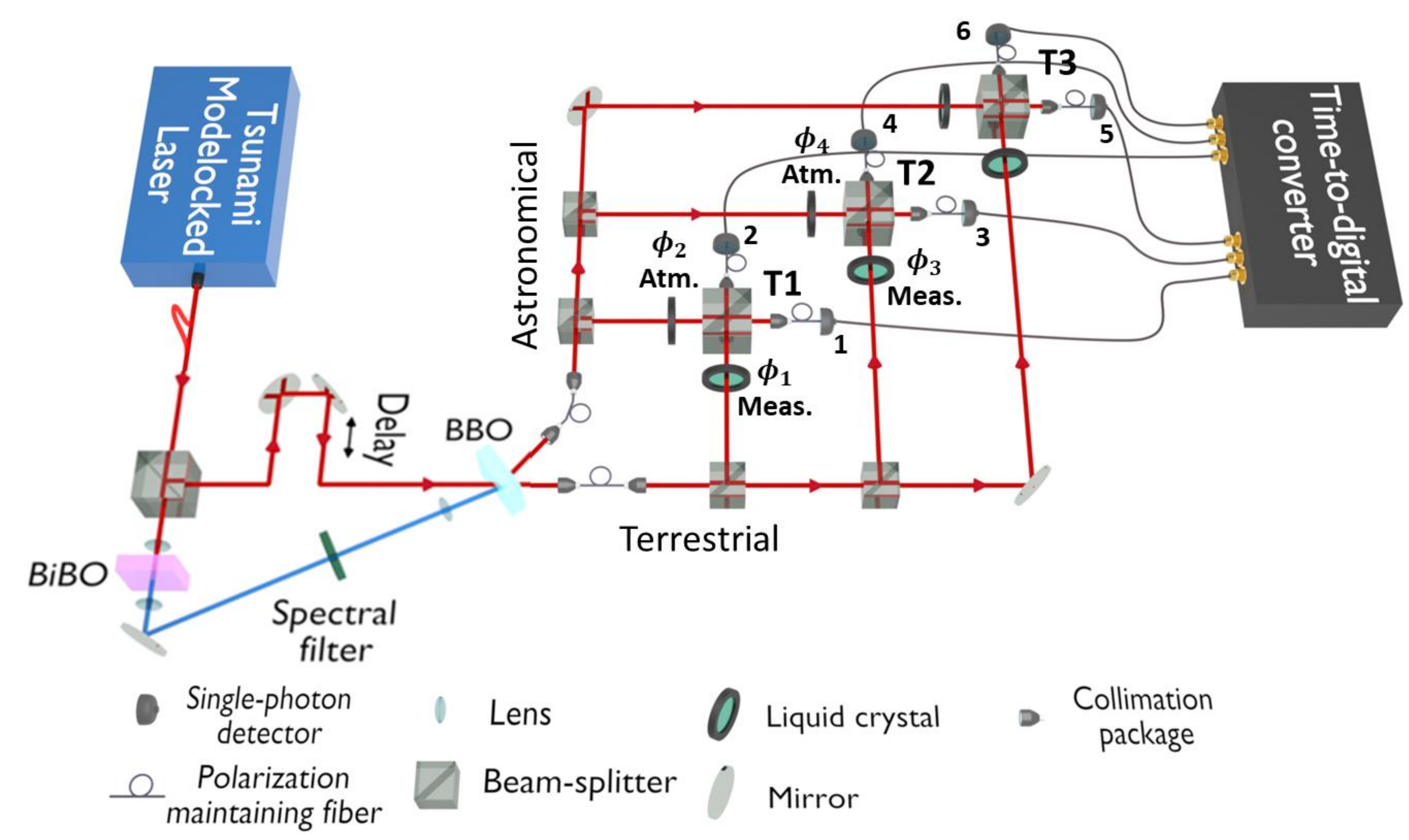


Quantum-Enhanced (Gottesman et al. Scheme†):

- Dependent on the brightness of the astronomical and terrestrial source
- Limited by our ability to create desired single photons



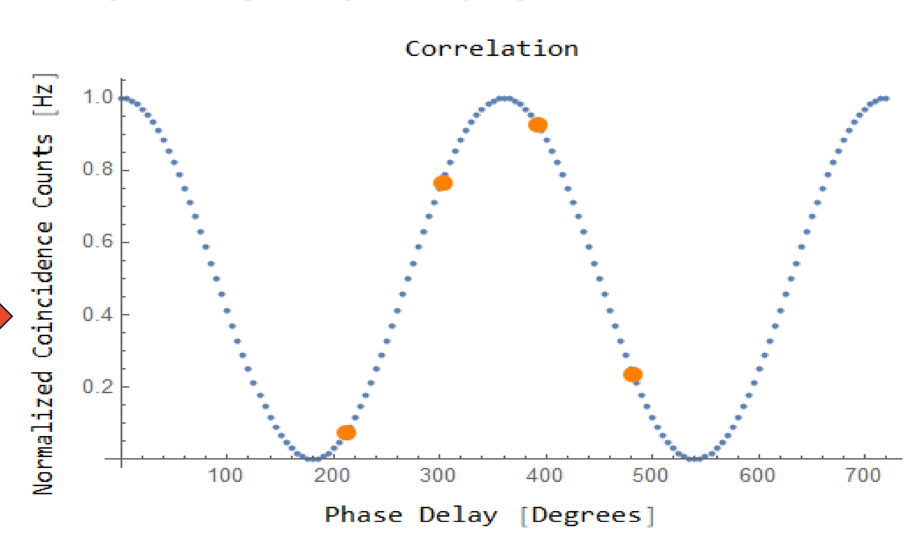
Experimental Setup



- "Terrestrial" and "astronomical" sources are photons created via spontaneous parametric down conversion
- Liquid crystals in the bottom arms apply the controlled phase input
- Liquid crystals in the left arms mimic atmospherical turbulence
- We look for coincidences across our telescopes for (anti-)correlation measurements, i.e., detectors 1 and 3(4)
- Two-photon interference fringes → visibility amplitude

2-Photon Interference

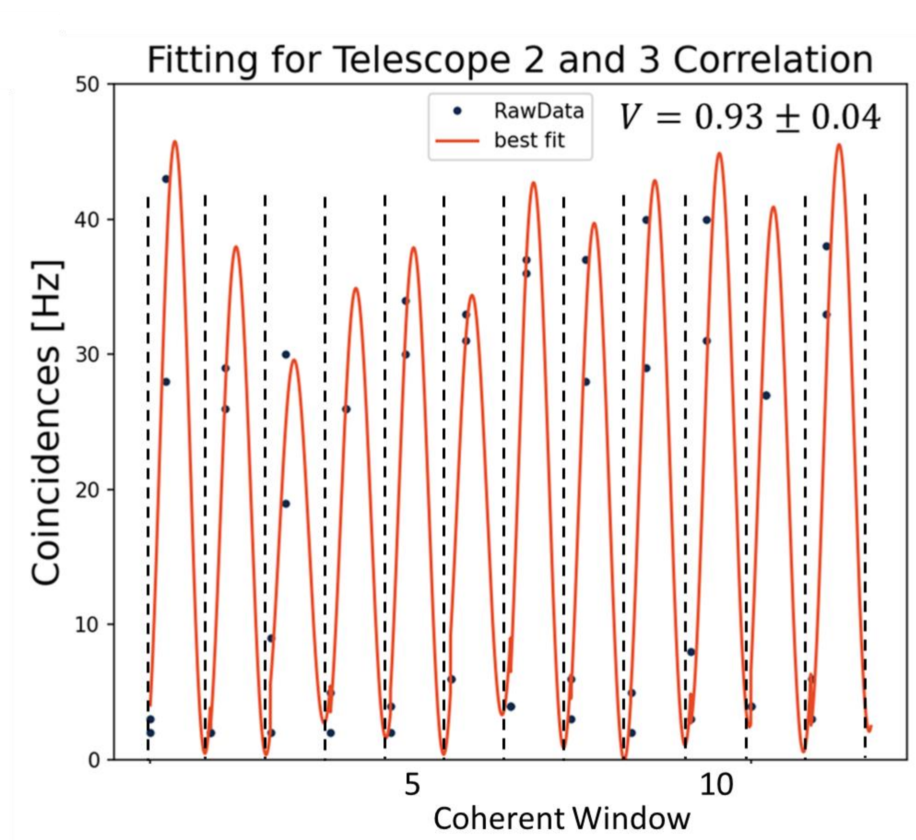
- With limited photon number, we use a two-phase setting scheme (0°,90°)
- Effectively 4 phases due to both beam splitter outputs
- Shown to be sufficient via numerical analysis



- Fringes obtained over 4 seconds consecutively for 150 total coherence windows

Fitting Function

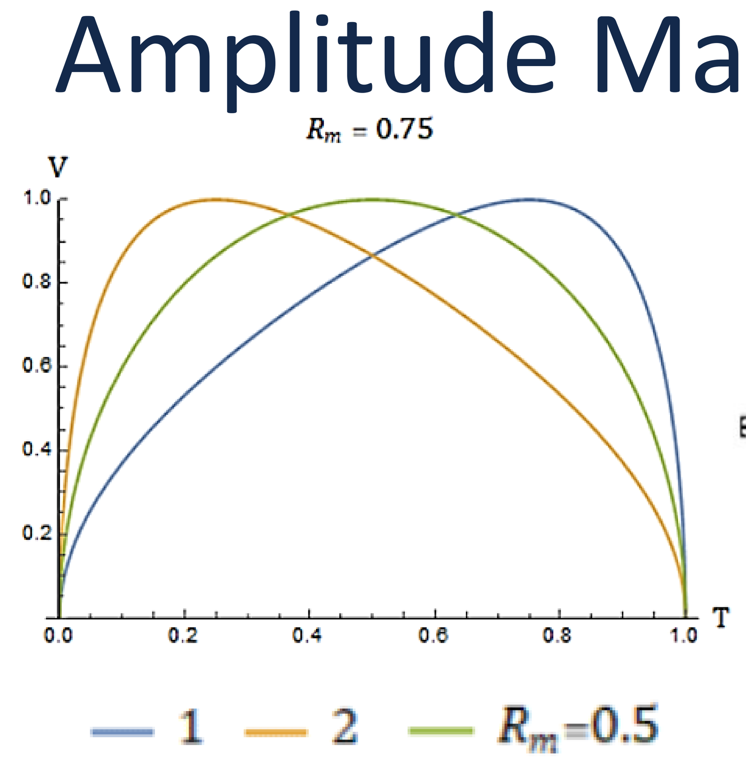
$$A_{i,j_k}\left(1-\mathcal{V}_{i,j}\,Cos\left(\varphi_{app}+\varphi_{atm_{i,j}}\right)\right),\quad i,j\in[1,3],k\in[1,4]$$

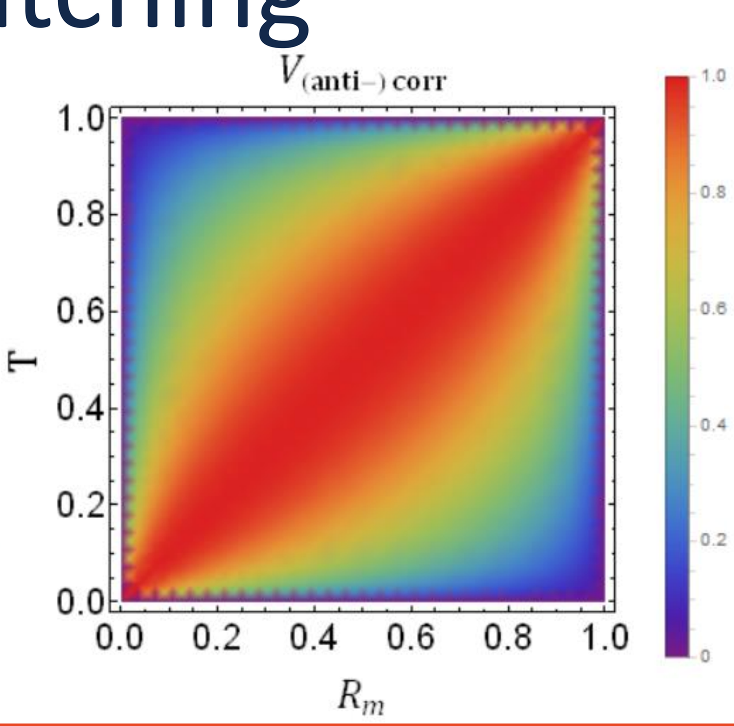


- No relative phases in a point source, accurate to average the visibility amplitudes $\mathcal{V}_{i,j}$
- Error determined via the standard deviation of the visibility amplitude determined over many coherence windows

Amplitude Matching

- $R_m = \frac{R_L}{R_R+R_L}$, $R_{L(R)}$ is photon rate into the left (right) telescope
- T is the transmission of the recombining BS for direct detection or the distributing BS for the single photons



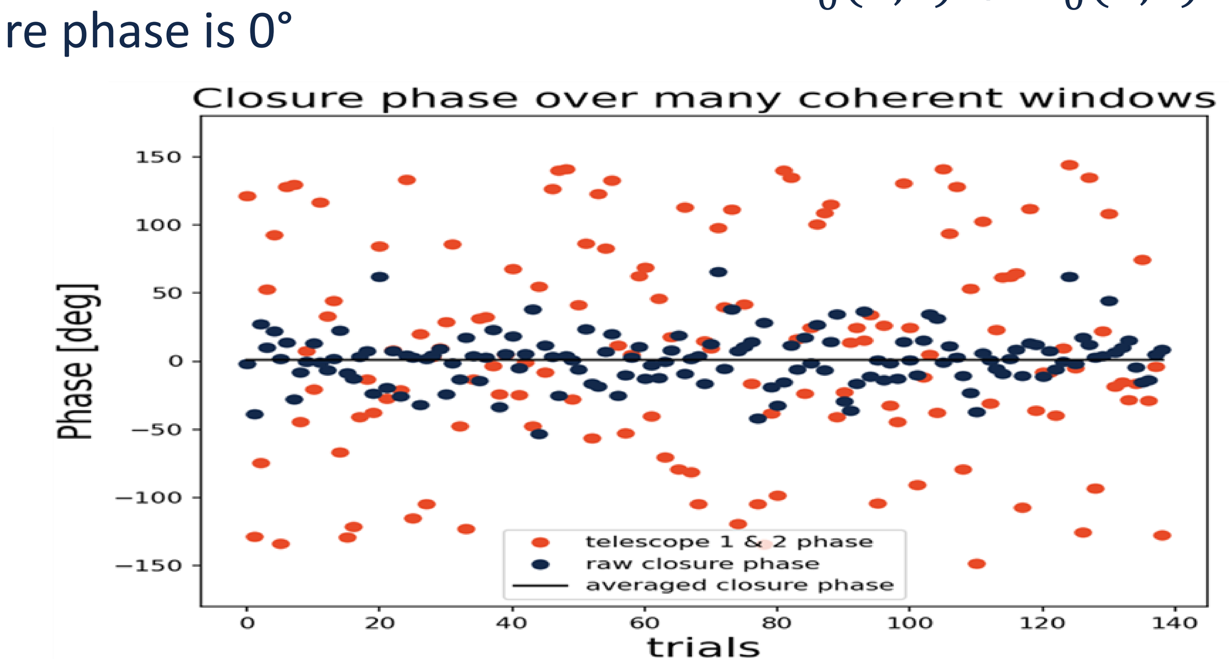


Closure Phase

- Closure phases calculated in sets of three telescopes to diminish turbulence effects on recovering source information
- For a point source, the closure phase is 0°

Observed = Intrinsic + Atmospheric

$$\Phi(1,2)=\Phi_0(1,2)+[\varphi(2)-\varphi(1)]$$
$$\Phi(2,3)=\Phi_0(2,3)+[\varphi(3)-\varphi(2)]$$
$$\Phi(3,1)=\Phi_0(3,1)+[\varphi(1)-\varphi(3)]$$
$$\Phi(1,2,3)\equiv\Phi(1,2)+\Phi(2,3)+\Phi(3,1)=\Phi_0(1,2)+\Phi_0(2,3)+\Phi_0(3,1)$$



- Extended sources require information on complex visibility $g_{i,j}=\mathcal{V}_{i,j}e^{i\phi_{i,j}}$
- When there is turbulence, we need to take the product $\mathcal{V}^c=|\overline{g_{12}g_{23}g_{31}}|$
- If we instead do $\mathcal{V}^i=|\overline{g_{12}}\ \overline{g_{23}}\ \overline{g_{31}}|$ we see a loss of information
- We will use the notation $\mathcal{V}=\overline{\mathcal{V}_{12}\mathcal{V}_{23}\mathcal{V}_{31}}$, as our true visibility

- Turbulence will be:
  - S - standard deviation less than 45°
  - L - uniform distribution over 360°

	$\tau(S)$	$\tau(L)$
$\mathcal{V}$	0.71 ± 0.17	0.66 ± 0.18
$\mathcal{V}^c$	0.69	0.59
$\mathcal{V}^i$	0.42	0.0002

Acknowledgements

This work was supported by the multi-university National Science Foundation Grant No. 1936321 - QII-TAQS: Quantum-Enhanced Telescopy. I would also like to thank our collaborators at the University of Oregon (Michael Raymer and Brian Smith) and the University of Michigan (John Monnier).

† D. Gottesman, T. Jennewein, and S. Croke, Longer-baseline telescopes using quantum repeaters, Phys. Rev. Lett.109,070503 (2012).