

# Is quantum noise always bad? Low-Light Shadow Imaging using Quantum-Noise Detection with a Camera.

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Ziqi Niu, Irina Novikova<sup>1</sup>  
Pratik J. Barge, Narayan Bhusal, Hwang Lee, Lior Cohen<sup>2</sup>

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Savannah Cuozzo



Irina Novikova



Jon Dowling (1955-2020)



Nikunj Kumar Prajapati



Ziqi Niu



Lior Cohen



Hwang Lee

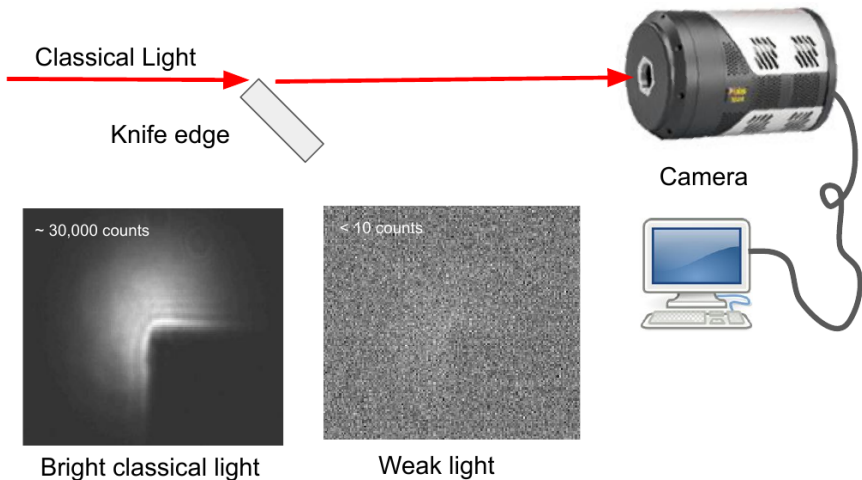


Pratik Barge

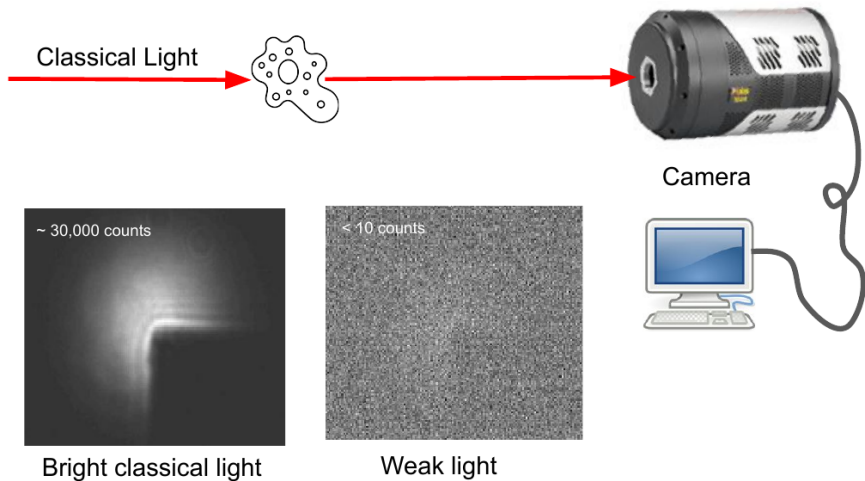


Narayan Bhusal

# From bright to low light imaging



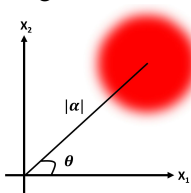
# From bright to low light imaging



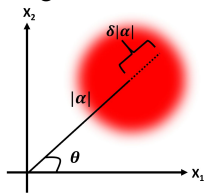


# Let's look at quantum picture

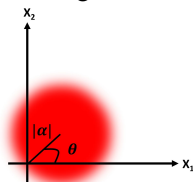
Bright state in



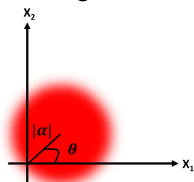
Bright state out



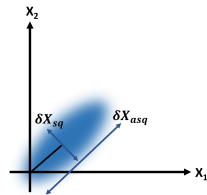
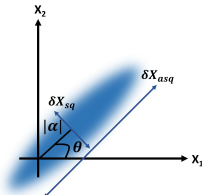
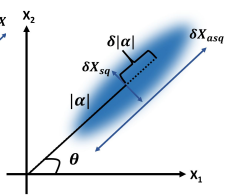
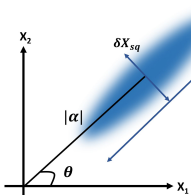
Low-light state in



Low-light state out

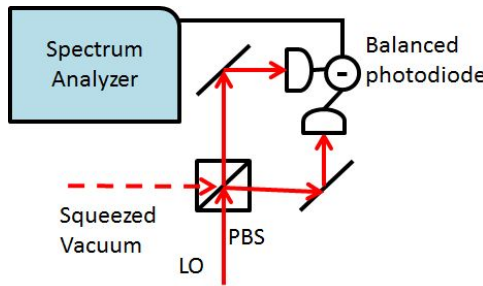
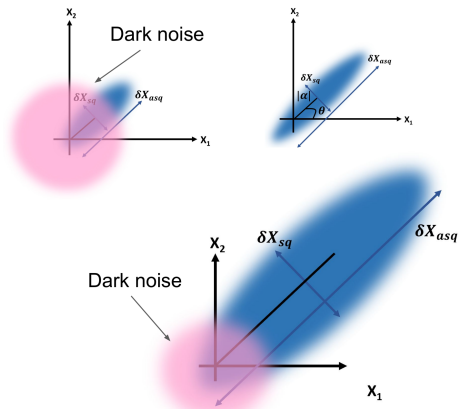


$$\alpha_{out}^2 = \alpha_{in}^2 T$$

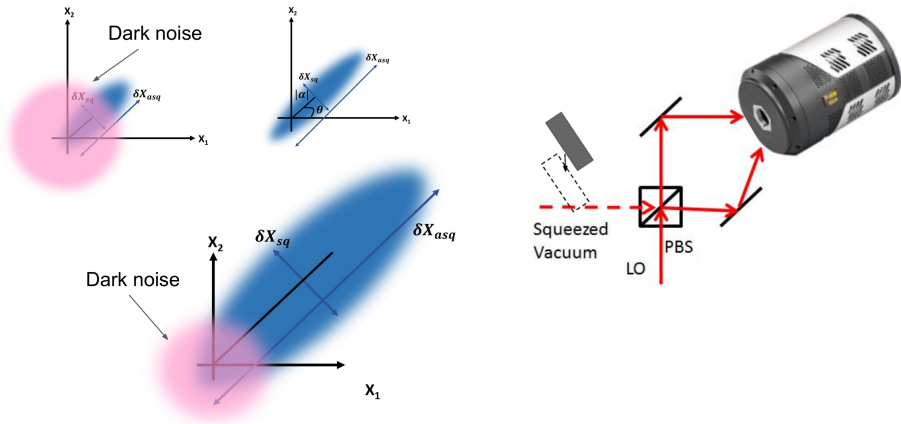


$$V = 1 + (\delta X_{sq/asq}^2 - 1) |\mathcal{O}|^2 T$$

# Detector dark noise

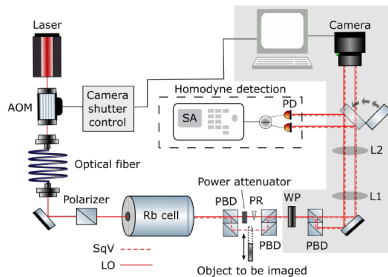
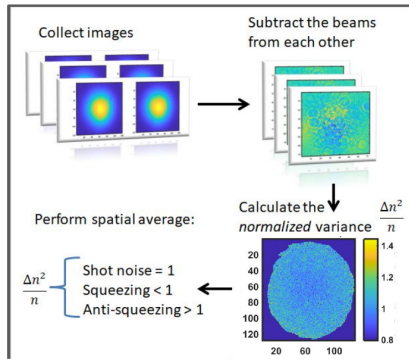


# Detector dark noise

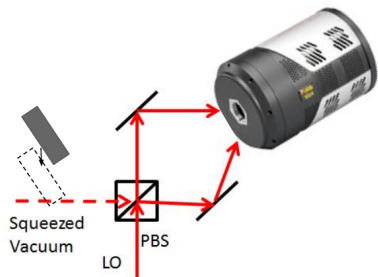


“Quantum-Limited Squeezed Light Detection with a Camera”, Phys. Rev. Lett. **125**, 113602

# Imaging quantum noise



# Imaging quantum noise with binning



$$V = 1 + (\delta X_{sq/asq}^2 - 1) |\mathcal{O}|^2 T$$

- Single pixel analysis = shot noise limited



Binning = 1

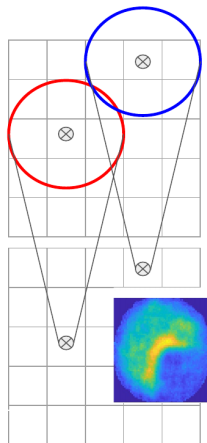


Binning = 4

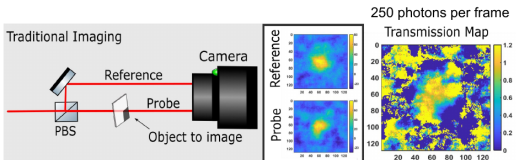
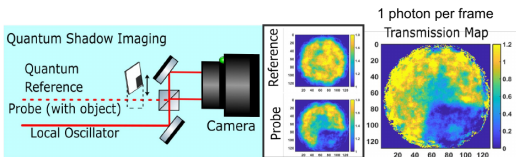


Binning = 16

- Binning pixels reveals non-classical statistics

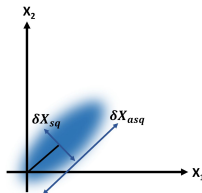


# Shadow imaging



$$V_{pr} = 1 + (\delta X_{ref}^2 - 1)|\mathcal{O}|^2 T$$

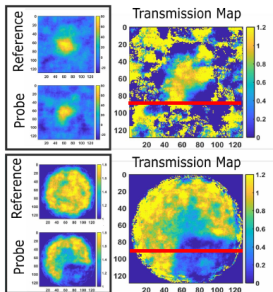
$$T = \frac{V_{pr} - 1}{V_{ref} - 1}$$



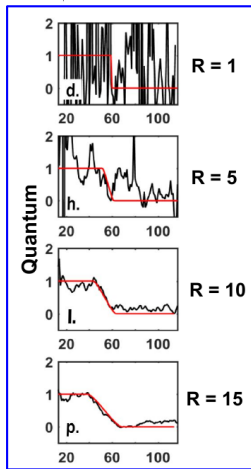
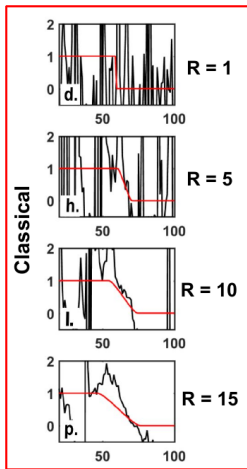
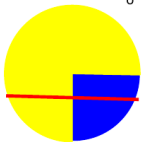
$$T = \frac{|\alpha_{pr}|^2}{|\alpha_{ref}|^2} = \frac{N_{pr}}{N_{ref}}$$

# Similarity Parameter

## Transmission Map Cross-section



Ideal case:  $T_o$



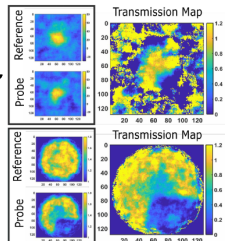
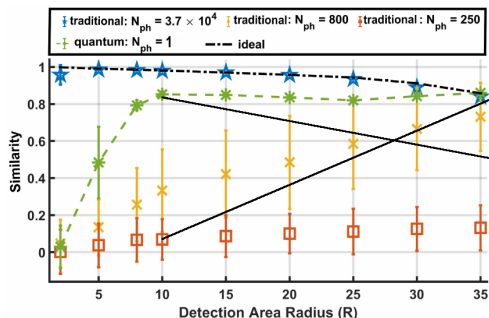
$$S = \frac{\sum T_{exp} T_o}{\sqrt{\sum T_{exp}^2 \sum T_o^2}}$$

# Similarity Parameter

$$S = \frac{\sum T_{exp} T_o}{\sqrt{\sum T_{exp}^2 \sum T_o^2}}$$



Savannah Couzzo



“Low-Light Shadow Imaging using Quantum-Noise Detection with a Camera”

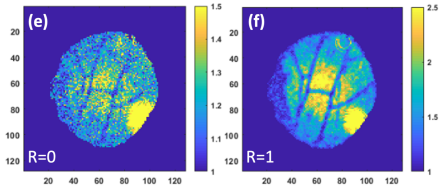
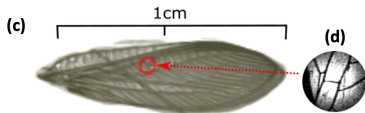
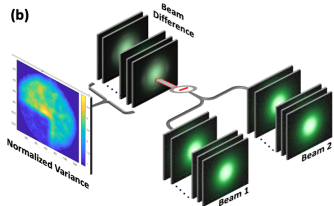
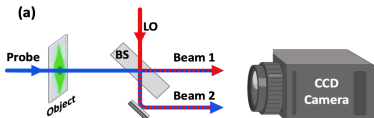
<https://arxiv.org/abs/2106.00785>



# Imaging with thermal light



Ziqi Niu



# Structural light imaging: single pixel camera

## Single-pixel imaging 12 years on: a review

GRAHAM M. GIBSON,<sup>1,2</sup> STEVEN D. JOHNSON,<sup>1,3</sup> AND MILES J. PADGETT<sup>1,4</sup>

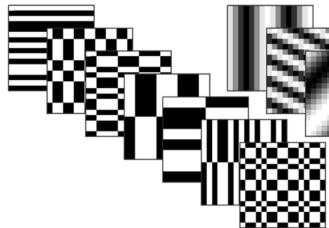
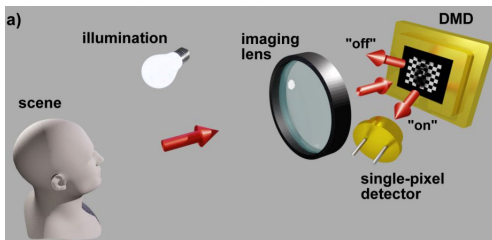
<sup>1</sup>School of Physics and Astronomy, University of Glasgow, Glasgow G12 8QQ, UK

<sup>2</sup>graham.gibson@glasgow.ac.uk

<sup>3</sup>steven.johnson@glasgow.ac.uk

<sup>4</sup>miles.padgett@glasgow.ac.uk

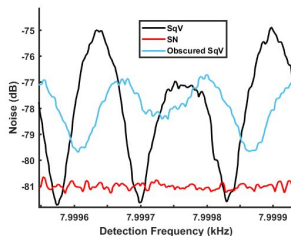
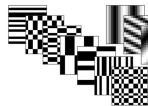
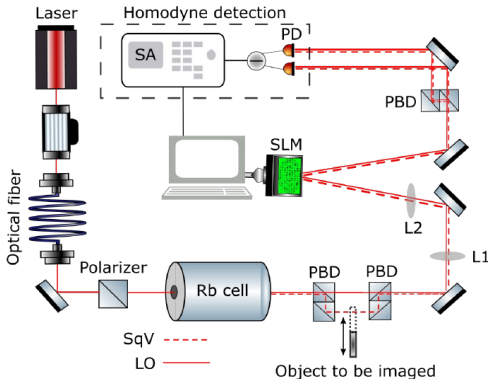
<https://www.gla.ac.uk/schools/physics/ourresearch/groups/optics/>



Reconstructed object

$$Ob(x, y) = \frac{1}{M} S_m P_m(x, y)$$

# Structural light imaging with quantum noise

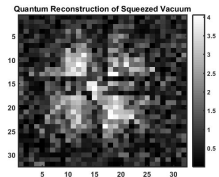
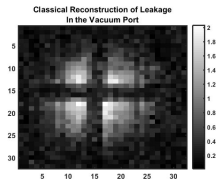
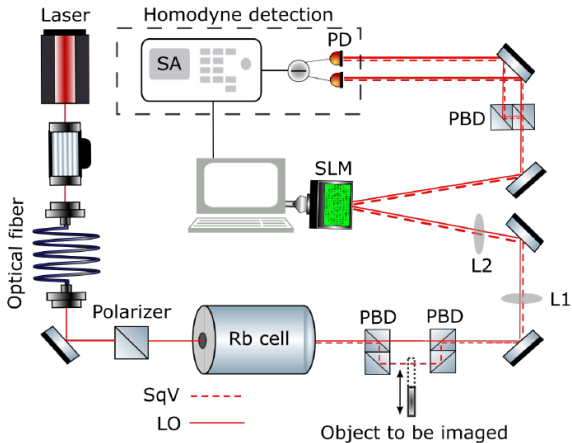


$$V_m = 1 + (\delta X_{sq/asq}^2 - 1) |O_m|^2$$

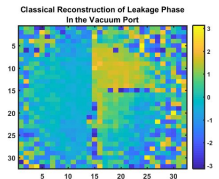
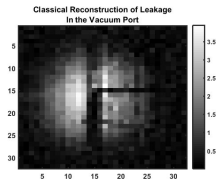
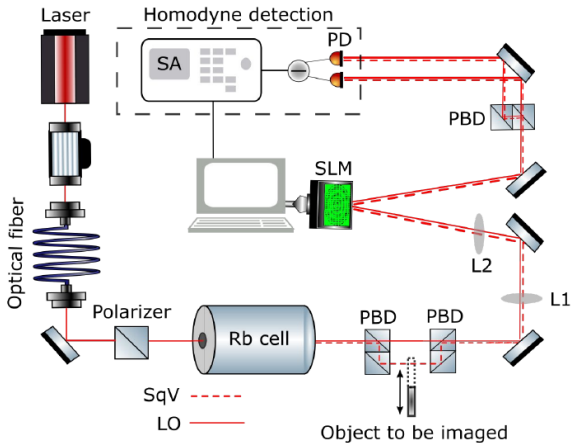
$$O_m = \int_A P_m u_{lo} u_q^* T dA$$

$$u_{lo} u_q^* T = \frac{1}{M} \sum O_m P_m(x, y)$$

# Structural light imaging with quantum noise



# Structural light imaging with quantum noise

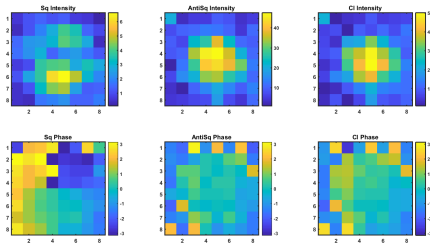
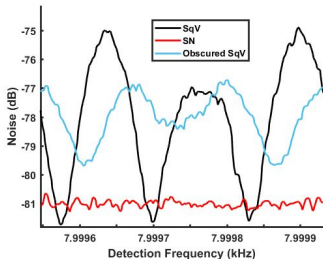


# Structural light using different quadratures

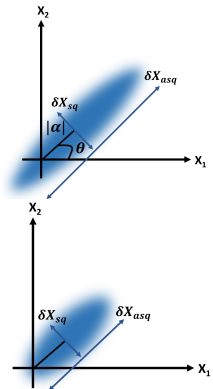
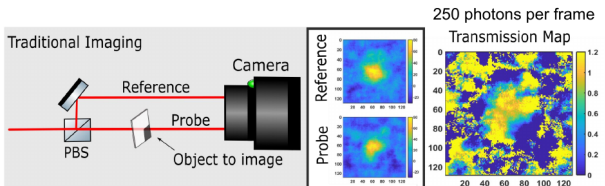
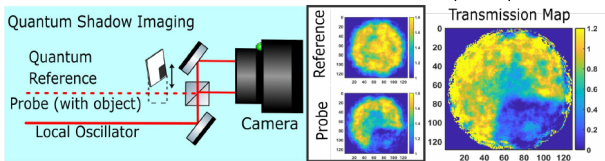
$$V_m = 1 + (\delta X_{sq/asq}^2 - 1) |\mathcal{O}_m|^2$$

$$\mathcal{O}_m = \int_A P_m u_{lo} u_q^* T dA$$

$$u_{lo} u_q^* T = \frac{1}{M} \sum \mathcal{O}_m P_m(x, y)$$



# Summary



“Low-Light Shadow Imaging using Quantum-Noise Detection with a Camera” <https://arxiv.org/abs/2106.00785>