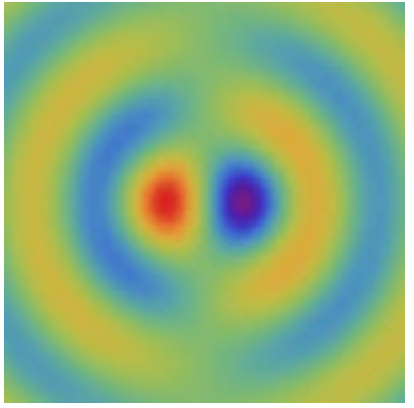
Quantum subwavelength imaging

Cosmo Lupo

Zixin Huang

Pieter Kok

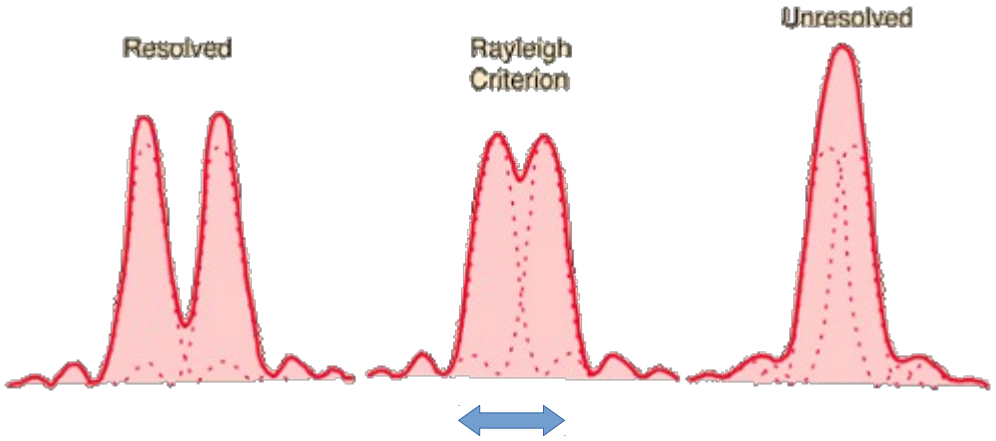


Summary

- Rayleigh resolution criterion
- Stastical and quantum inference
- Sub-wavelenght quantum resolution
- Noisy detectors and ultimate limits
- Towards applications?

Back to the textbooks

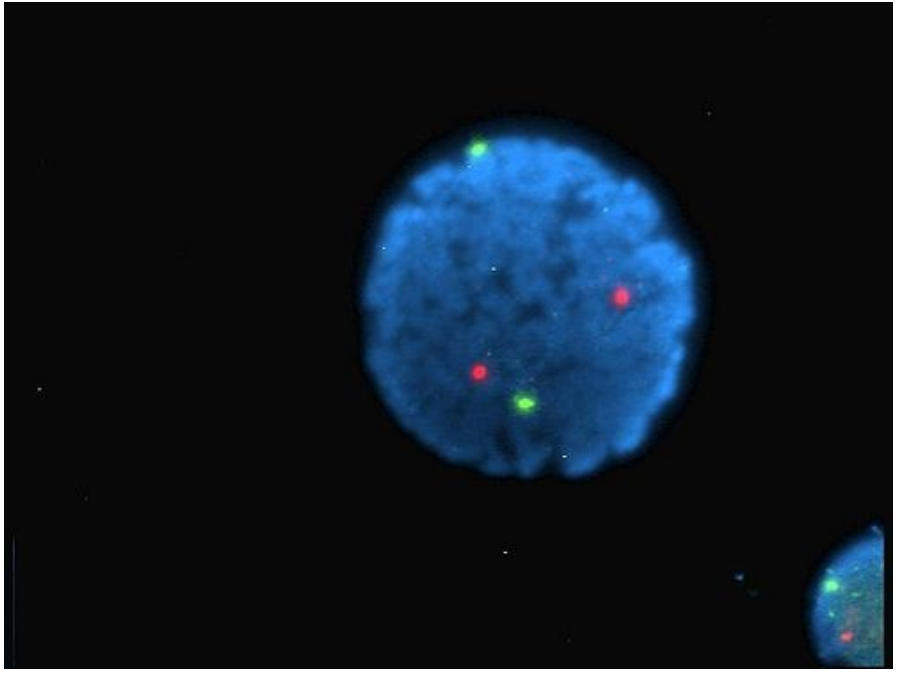
Rayleigh resolution criterion



Wavelength / Rayleigh length

$$\lambda \qquad \lambda \frac{R}{D}$$

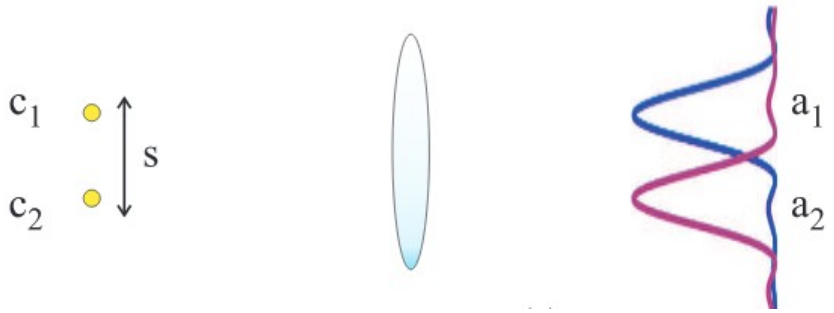
Fluorescence microscopy



Nobel Prize in Chemistry 2014

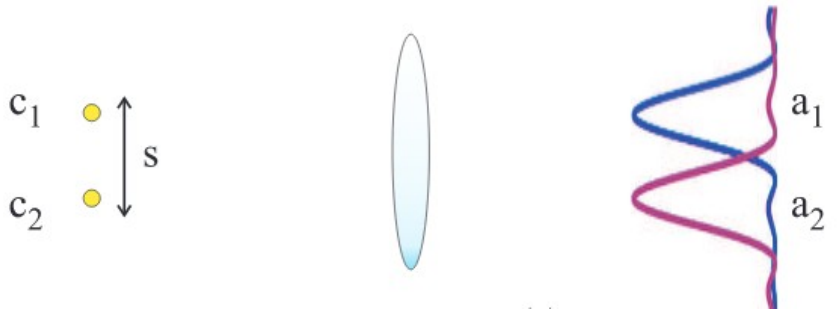
Spot on information theory

Statistical inference



Spot on information theory

Statistical inference

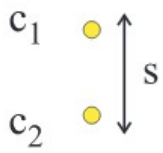


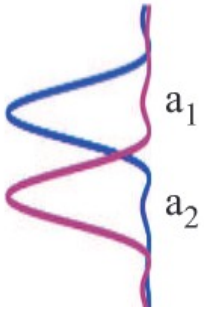
$$n \to f_n(x|s)$$

$$\lim_n f_n(x|s) = p(x|s)$$

Spot on information theory

Statistical inference



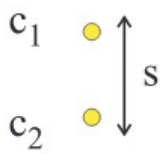


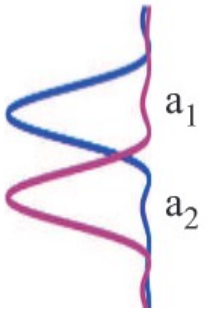
$$n \rightarrow f_n(x|s)$$

$$\lim_n f_n(x|s) = p(x|s)$$

Spot on information theory

Statistical inference





$$n \rightarrow f_n(x|s)$$

$$\lim_n f_n(x|s) = p(x|s)$$

$$\hat{s}$$

Spot on information theory

Statistical inference

Unbiased estimator

$$\hat{s} : \langle \hat{s} \rangle = s$$

Spot on information theory

Statistical inference

Unbiased estimator

$$\hat{s} : \langle \hat{s} \rangle = s$$

Cramer-Rao bound

$$\Delta \hat{s} \geqslant \frac{1}{\sqrt{n F}}$$

Spot on information theory

Statistical inference

Unbiased estimator

$$\hat{s} : \langle \hat{s} \rangle = s$$

Cramer-Rao bound

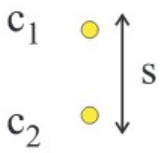
$$\Delta \hat{s} \geqslant \frac{1}{\sqrt{n F}}$$

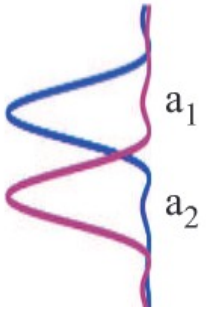
Fisher information

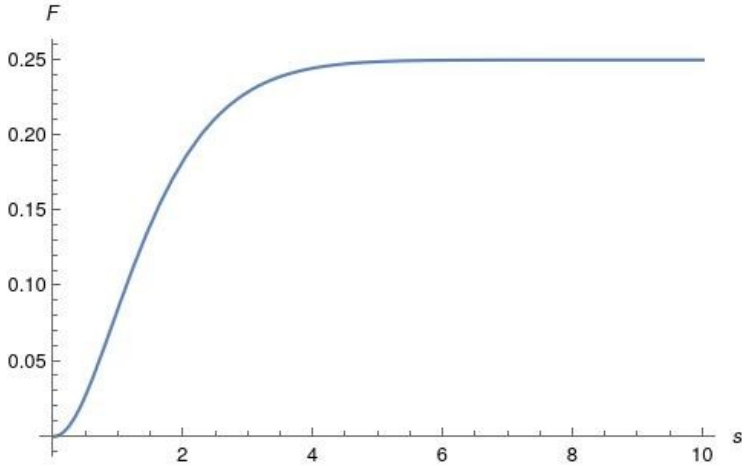
$$F = \int dx \; p(x|s) \left(\frac{\partial_s p(x|s)}{p(x|s)} \right)^2$$

Spot on information theory

Statistical inference



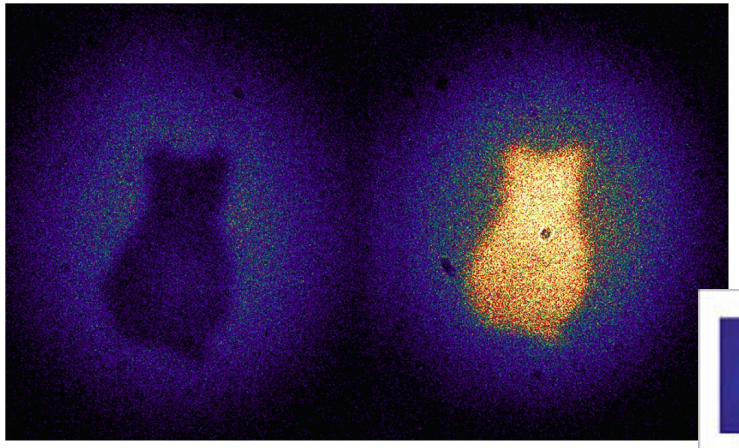




Cramer-Rao bound

$$\Delta \hat{s} \geqslant \frac{1}{\sqrt{n F}}$$

Quantum imaging



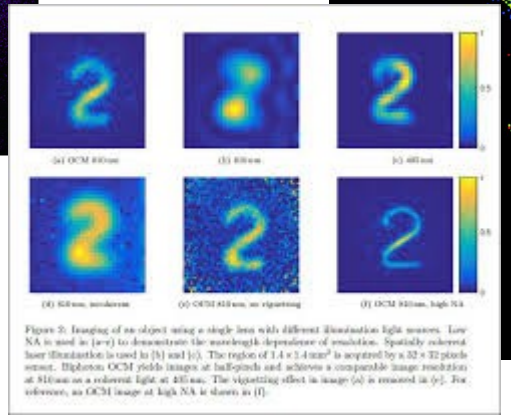
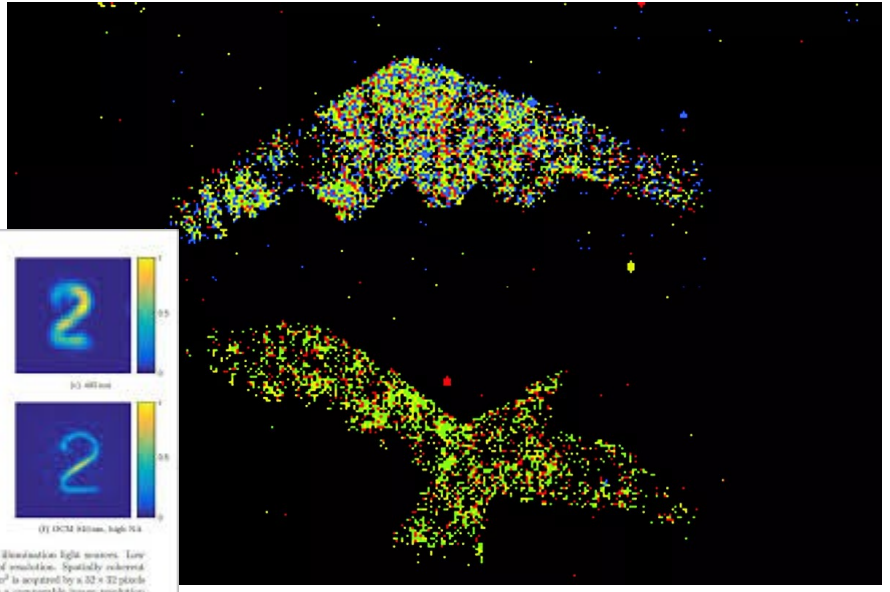
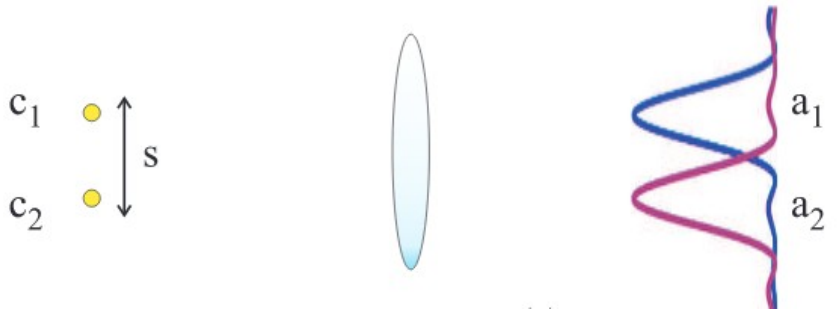


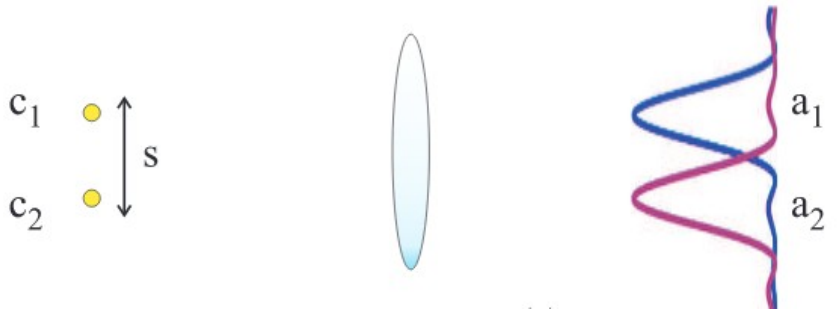
Figure 2: Imaging of an object using a single lens with different illumination light sources. Low NA is used in (a-e) to demonstrate the wavelength dependence of resolution. Spatially coherent laser illumination is used in (b) and (c). The region of $1.4 \times 1.4\,\mathrm{mm}^2$ is acquired by a 32×32 pixels sensor. Righton OCM yields images at half-pitch and achieves a comparable image resolution at 810 nm as a coherent light at 405 nm. The vignetting effect in image (a) is removed in (e). For reference, an OCM image at high NA is shown in (f).



Quantum information theory

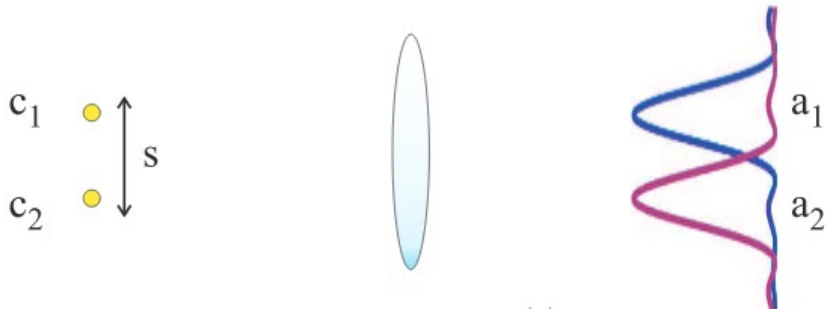


Quantum information theory



$$n \rightarrow \rho^{\otimes n}(s)$$

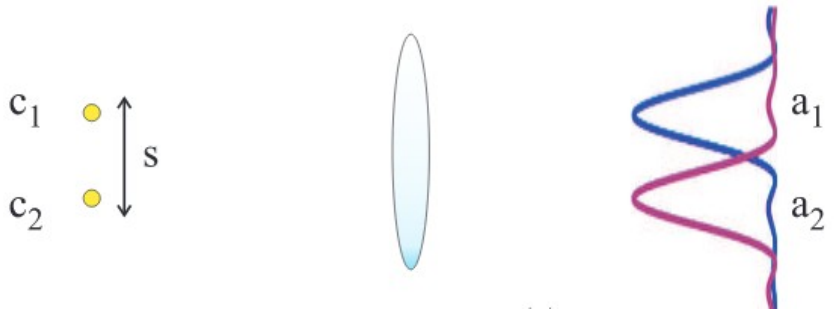
Quantum information theory



$$n \rightarrow \rho^{\otimes n}(s)$$

Measurement apparatus

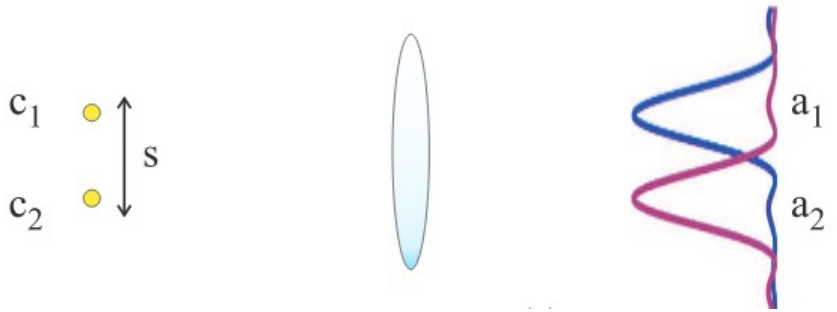
Quantum information theory



$$n \rightarrow \rho^{\otimes n}(s)$$

Measurement apparatus

Quantum information theory



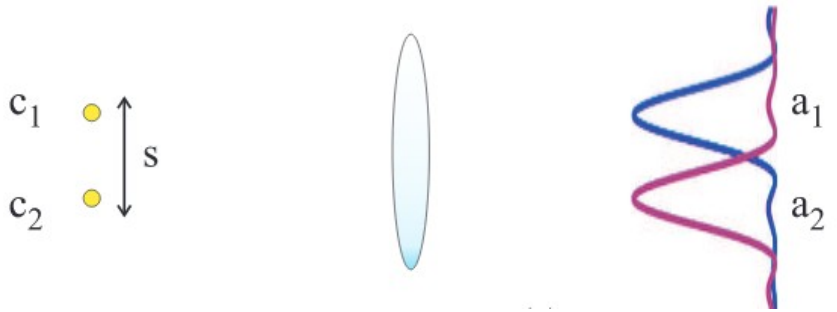
Quantum Cramer-Rao bound

$$\Delta \hat{s} \geqslant \frac{1}{\sqrt{n\,QF}}$$

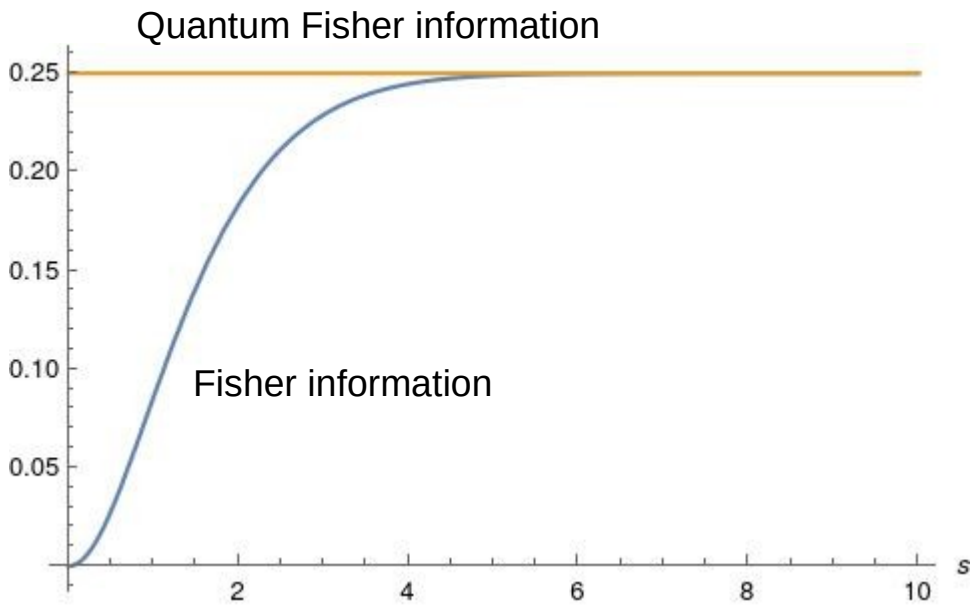
Quantum Fisher information

$$QF = Tr\left(\rho L_{\rho}^{2}\right)$$

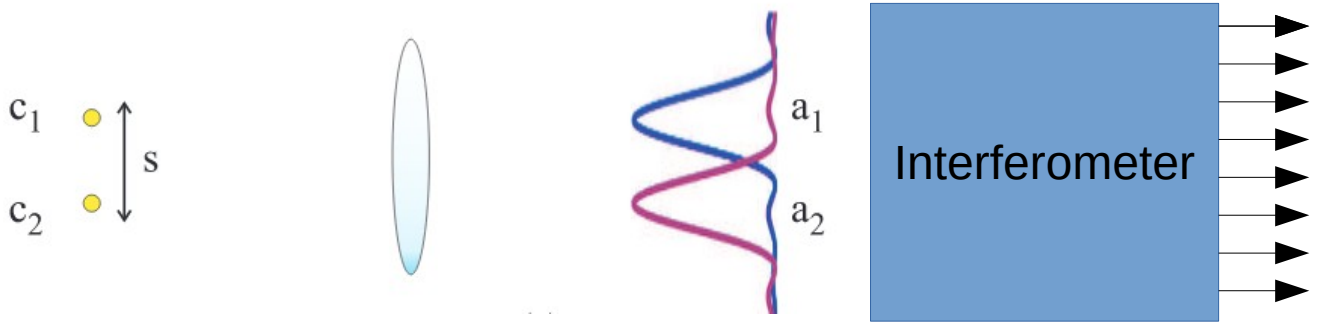
Quantum super-resolution



Regime of faint signals,
less than 1 photon
detected in average



Explicit measurement



Regime of faint signals,
less than 1 photon
detected in average

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Quantum Theory of Superresolution for Two Incoherent Optical Point Sources

Mankei Tsang, Ranjith Nair, and Xiao-Ming Lu
Phys. Rev. X **6**, 031033 – Published 29 August 2016

Physics See Viewpoint: Unlocking the Hidden Information in Starlight

Journal
Contemporary Physics ›
Volume 60, 2019 - Issue 4

Review articles

Resolving starlight: a quantum perspective

Mankei Tsang

Pages 279-298 | Received 05 Oct 2019, Accepted 24 Feb 2020, Published online: 11 Mar 2020

Download citation https://doi.org/10.1080/00107514.2020.1736375

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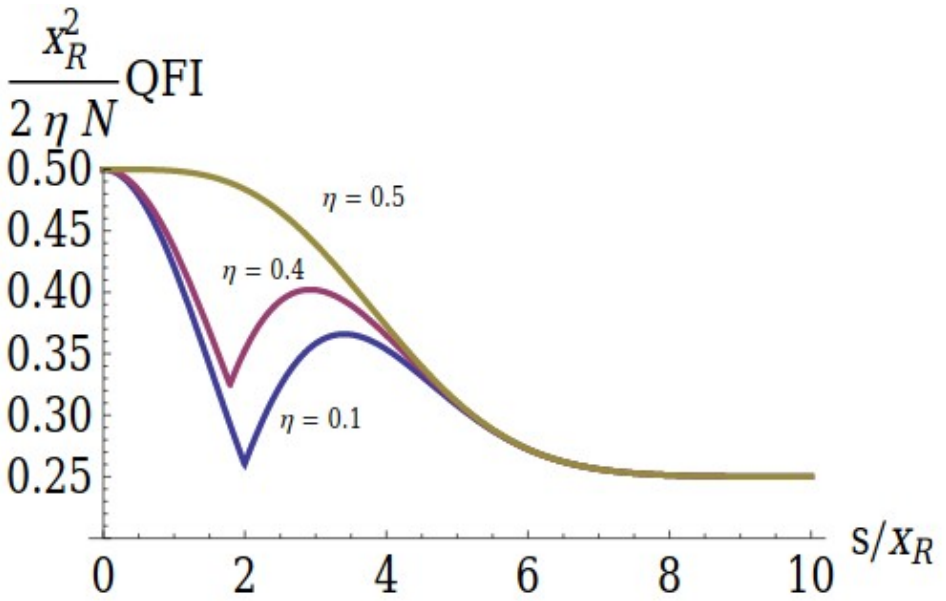
Editors' Suggestion

Ultimate Precision Bound of Quantum and Subwavelength Imaging

Cosmo Lupo and Stefano Pirandola

Phys. Rev. Lett. **117**, 190802 – Published 4 November 2016

Engineered, entangled emitters, can be super-resolved below the wavelength



What about detector noise?

International Journal of Quantum Information | Vol. 18, No. 01, 1941015 (2020)

Resolution limits of spatial mode demultiplexing with noisy detection

Yink Loong Len, Chandan Datta, Michał Parniak and Konrad Banaszek

https://doi.org/10.1142/S0219749919410156 | **Cited by:** 1

Subwavelength quantum imaging with noisy detectors

Cosmo Lupo

Phys. Rev. A **101**, 022323 – Published 19 February 2020

arXiv.org > quant-ph > arXiv:2004.07228

Quantum Physics

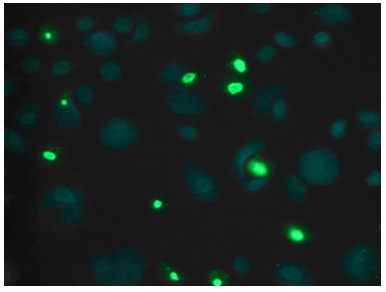
[Submitted on 15 Apr 2020]

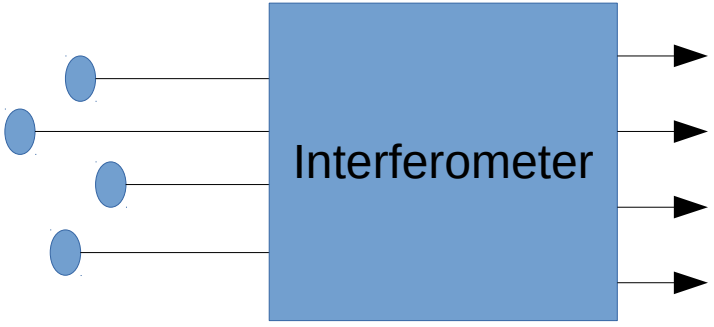
Superresolution limits from measurement crosstalk

Manuel Gessner, Claude Fabre, Nicolas Treps

$$\lambda \rightarrow \frac{\lambda}{\sqrt{SNR}}$$

Moving beyond textbook problems





Regime of faint signals, less than 1 photon detected in average

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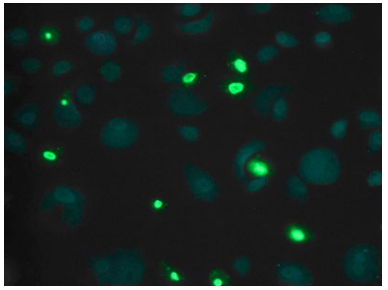
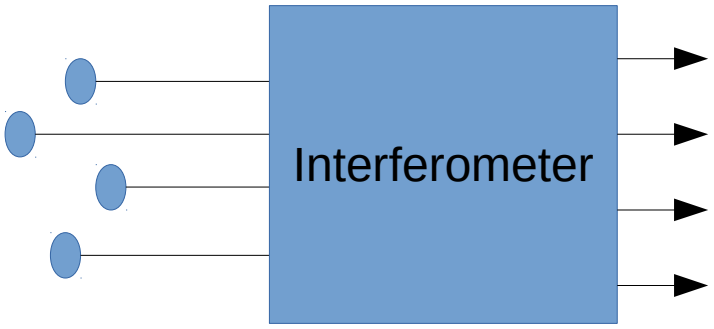
Quantum Limits to Incoherent Imaging are Achieved by Linear Interferometry

Cosmo Lupo, Zixin Huang, and Pieter Kok

Phys. Rev. Lett. **124**, 080503 – Published 27 February 2020

Conclusions





Quantum imaging beats classical limits

Going beyond faint signals?

Using interferometers to solve practical imaging problems?

Patter recognition?

Benchmarking of realistic imaging problems


ANY
QUESTIONS?