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The Abdus Salam International Centre for Theoretical Physics

Miles Padgett

Kelvin Chair of Natural Philosophy

3D Computational Ghost Imaging

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Outline

Ghost Imaging (with entangled light)

Ghost Imaging with classical light

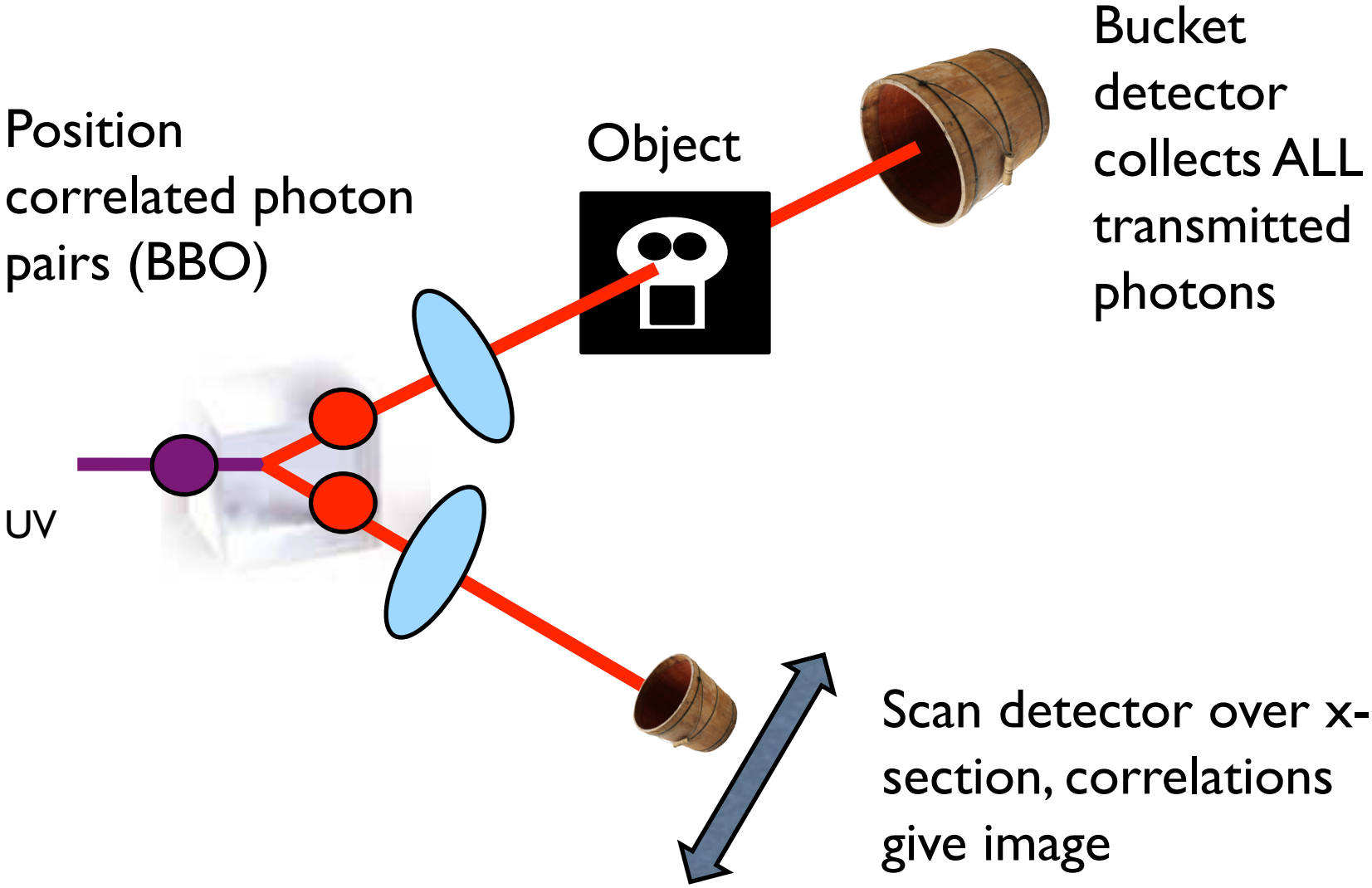
Computational Ghost Imaging ≈ Single Pixel Camera

3D recon using image shadings (Shape from Shade)

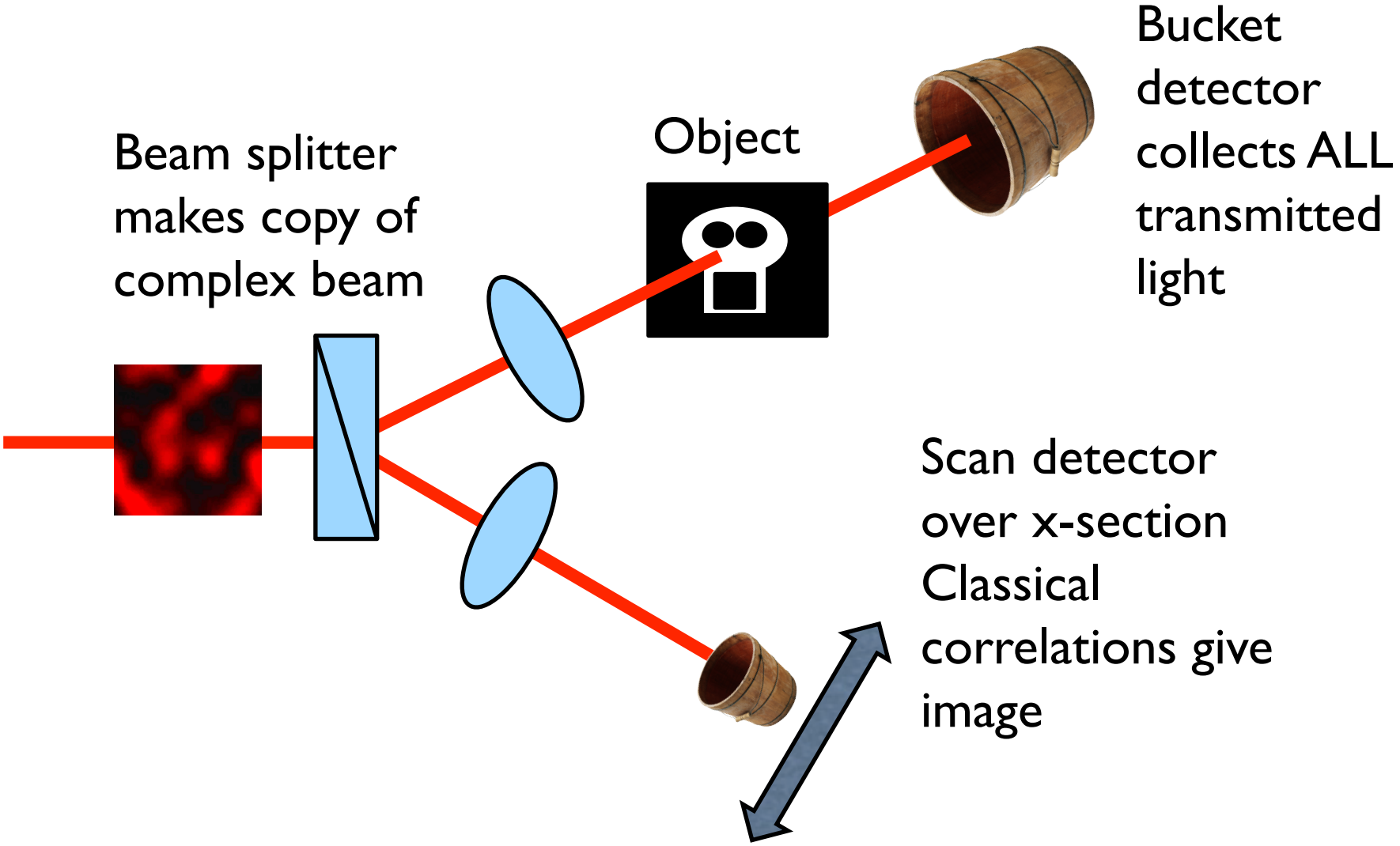
3D Computational Ghost Imaging (shape from shade with a single pixel camera)

Ghost Imaging (with entangled light)

Ghost imaging with (quantum) correlated light



Ghost imaging with (classical) correlated light



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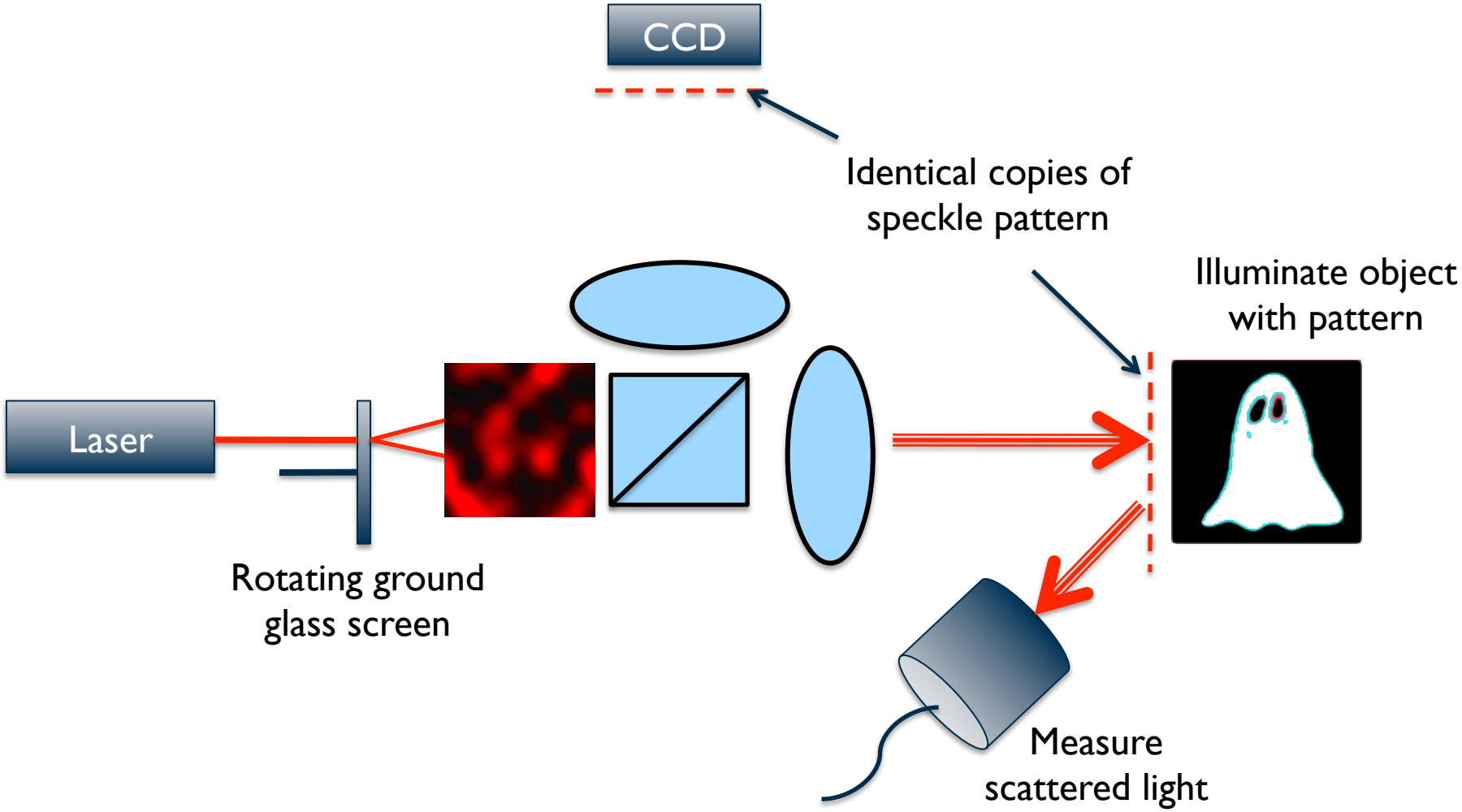
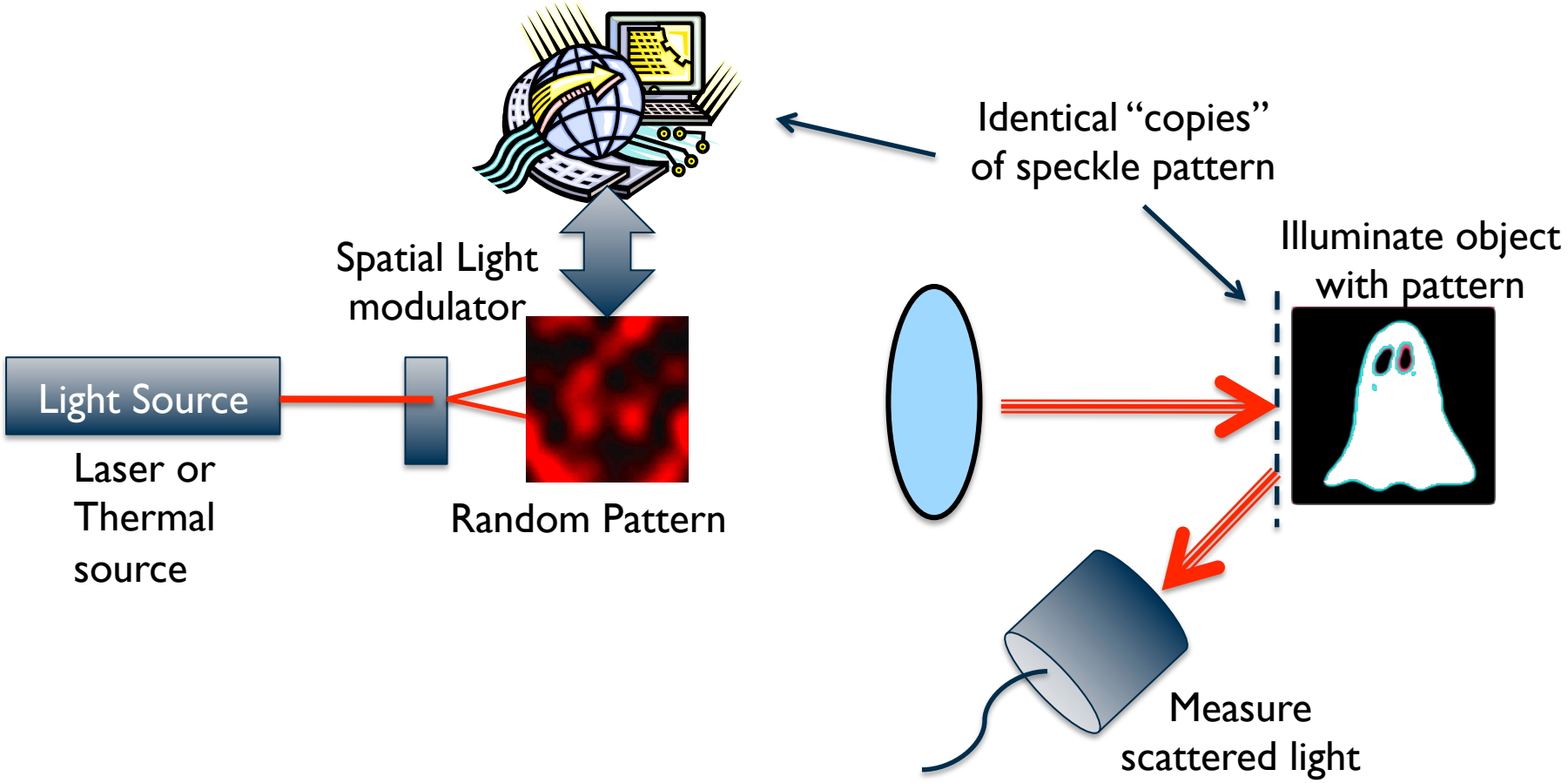
A Classical Ghost Imager



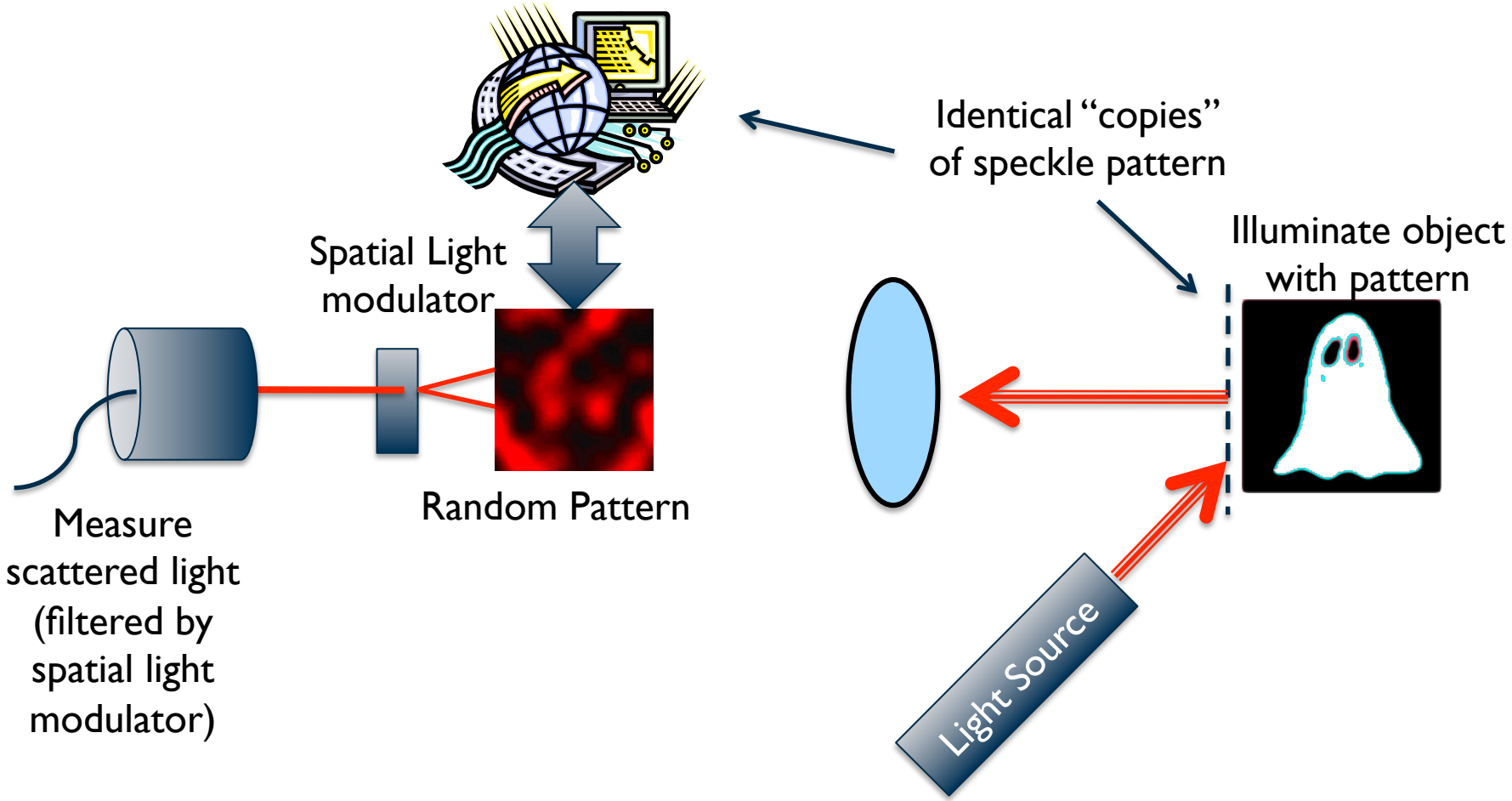
A Computational Ghost Imager

- Generate deterministic speckle using spatial light modulator, no need for CCD – the computer already knows!



A single-pixel Imager

- Filter the scattered light – use all the same algorithms as a computational ghost imager



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An interesting discussion

What are the relative merits of computational ghost imaging (projecting a random pattern) vs. single pixel camera (measuring a random pattern)

- Optical efficiency?
- Covert?
- Ranging?

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Computational Ghost Imaging in 3D


Dr. Matthew Edgar


Mr. Baoqing Sun

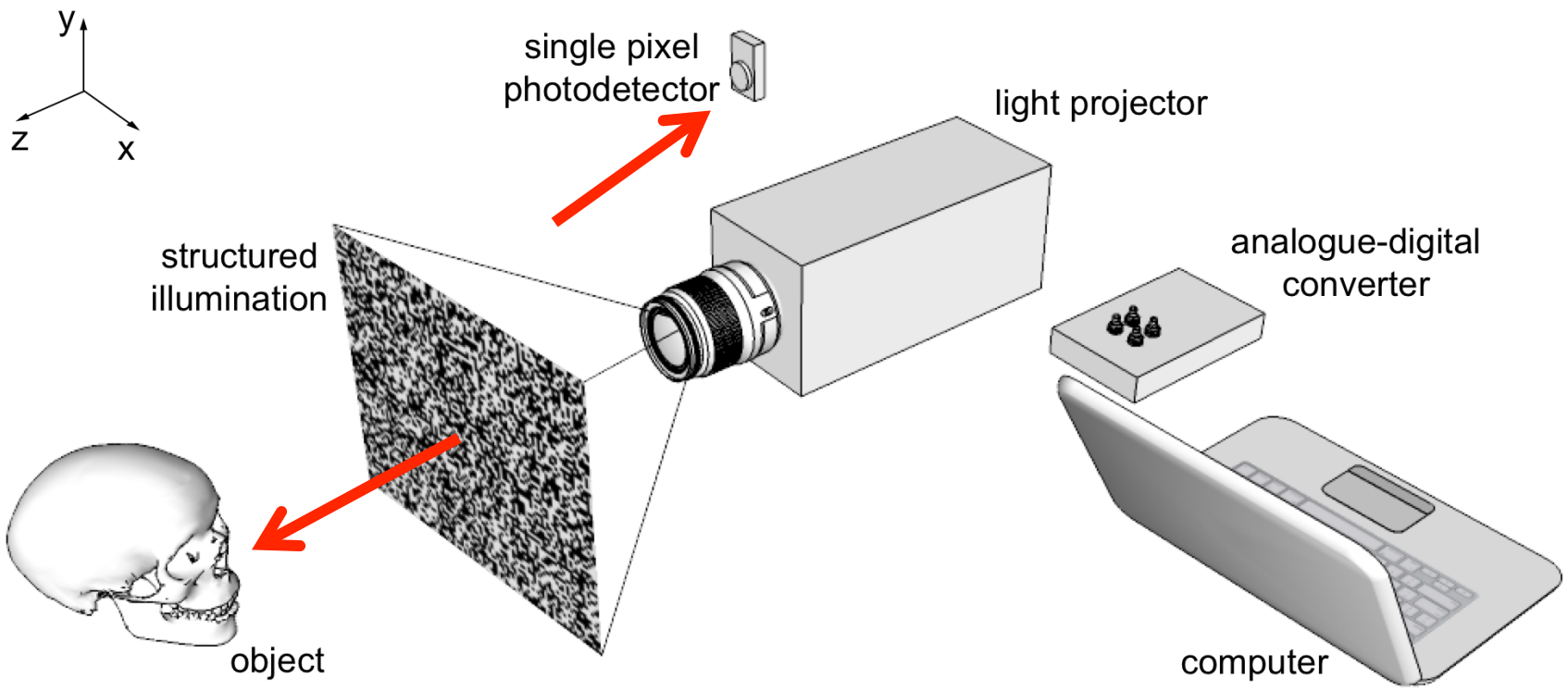

Mr. Stephen Welsh


Dr. Richard Bowman

and L E Vittert and Prof A Bowman (Maths)

Ghost imaging with classical light

Experimental setup for 3D computational ghost imaging



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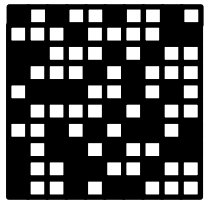
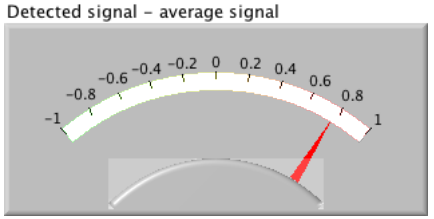
Projecting a series of random pattern

Traditional Ghost Imaging

$$\sum_{N}$$



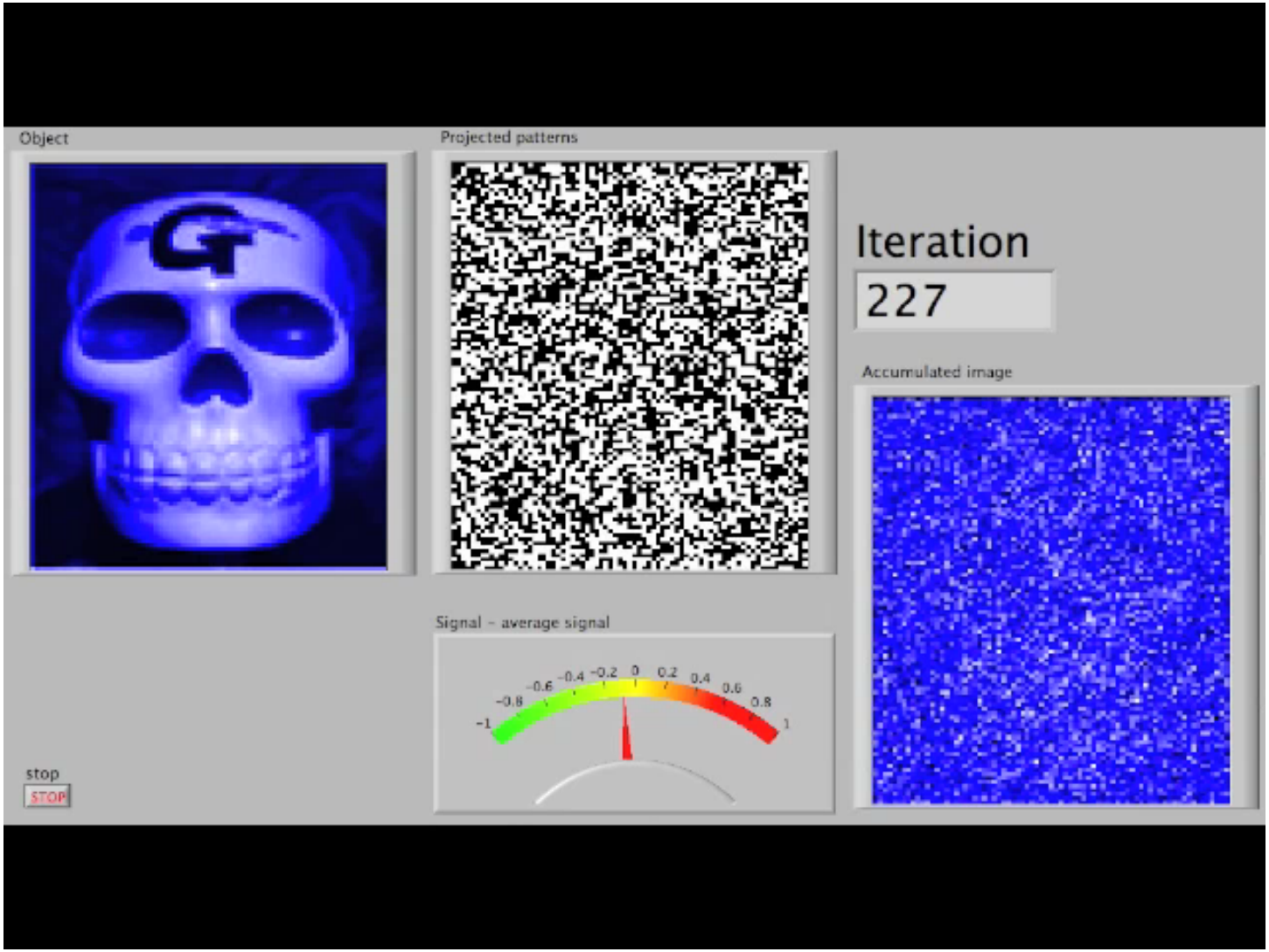


random pattern X (detector signal - average detector signal)

≈ Need N different patterns to give N pixel image

Or use "compressive" techniques (c.f. JPEG) to do better!

Traditional Ghost Imaging



Ghost imaging with classical light

Iterative reconstruction of 2D image

Test object (toy skull)

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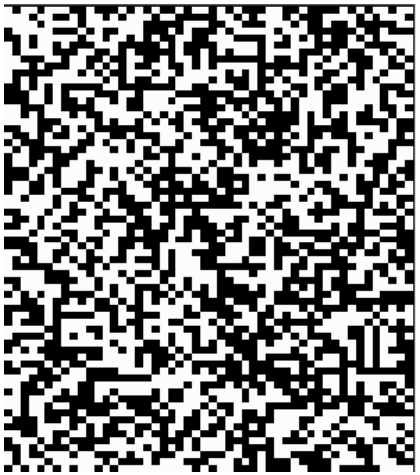
Compressive Ghost Imaging

50 x 67 pixels

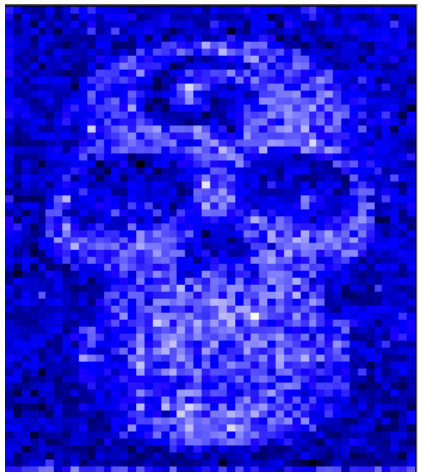
Object & example illumination



3350 patterns

0% noise

Recon by direct matrix inversion



5% noise

Recon regularised

L1 norm

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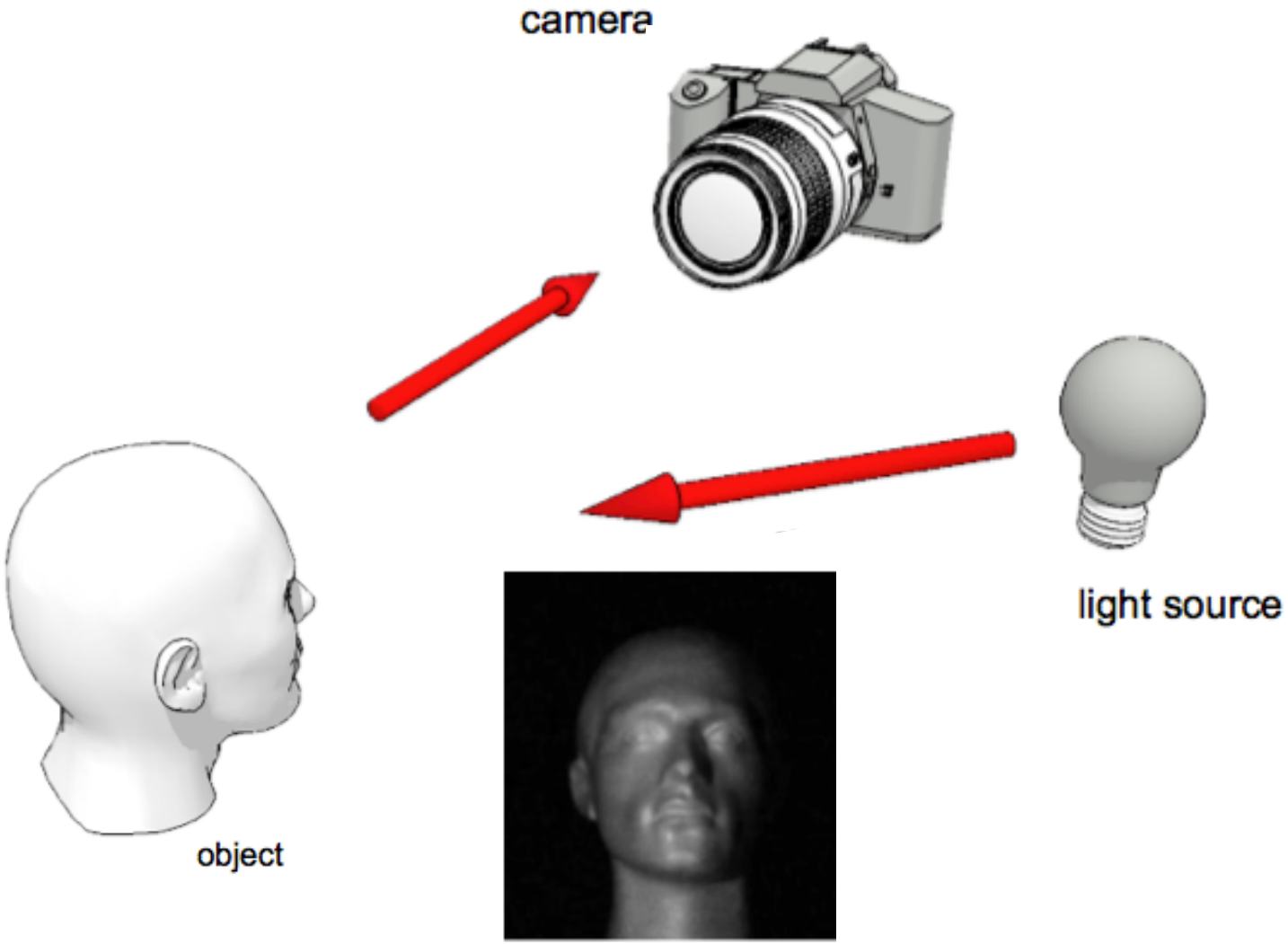
Normal Imaging with “off-axis” illumination



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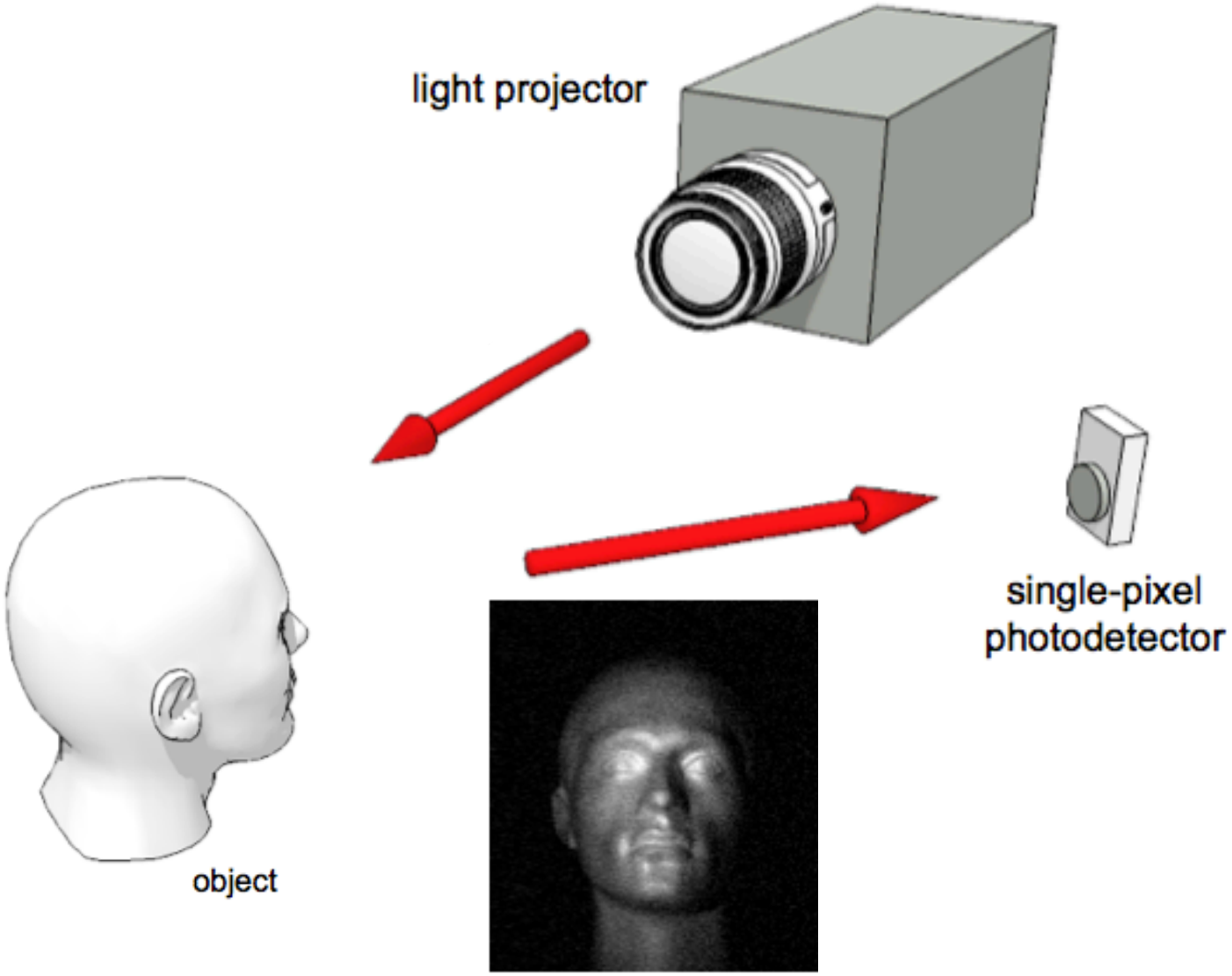
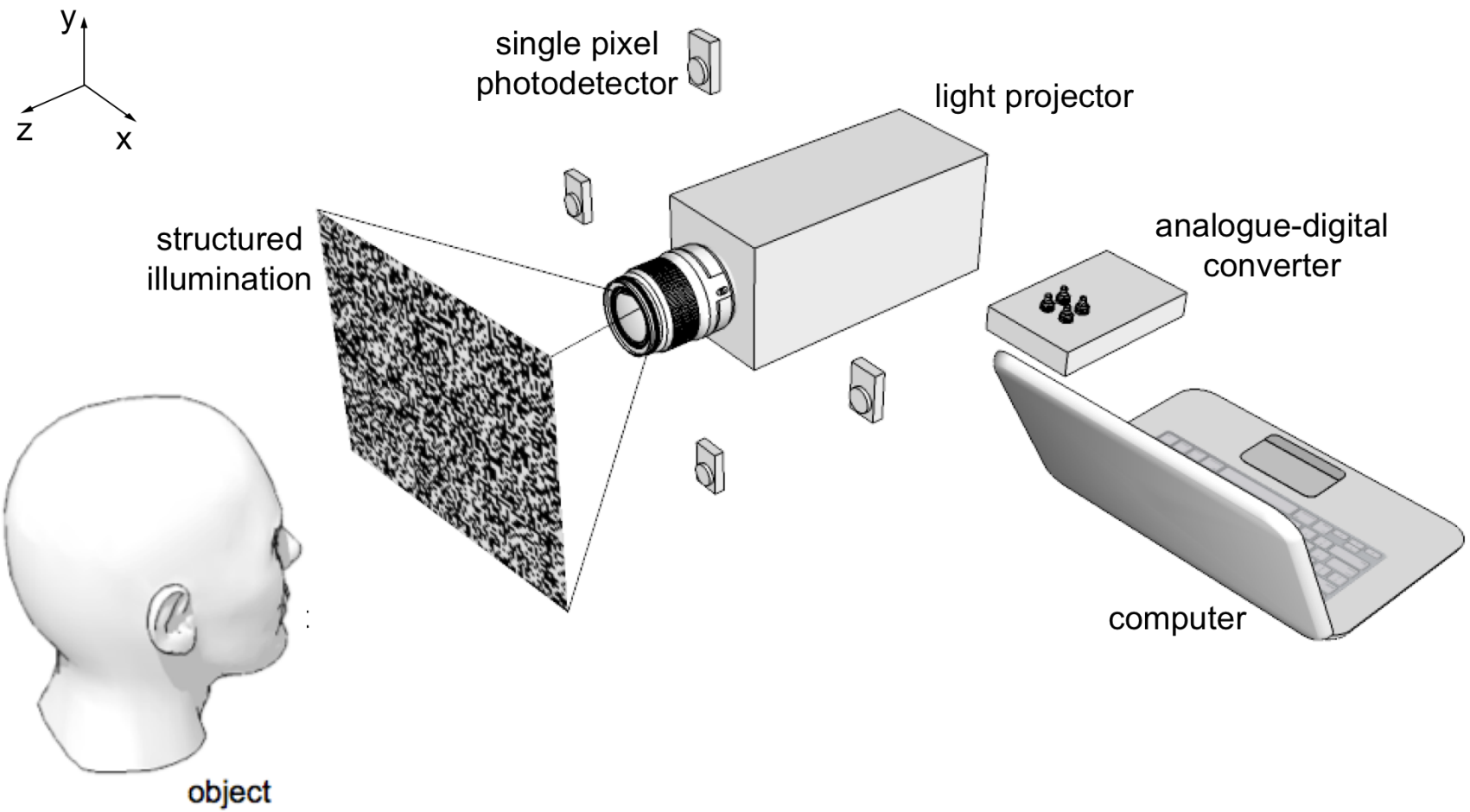
Ghost Imaging with “off-axis” detection



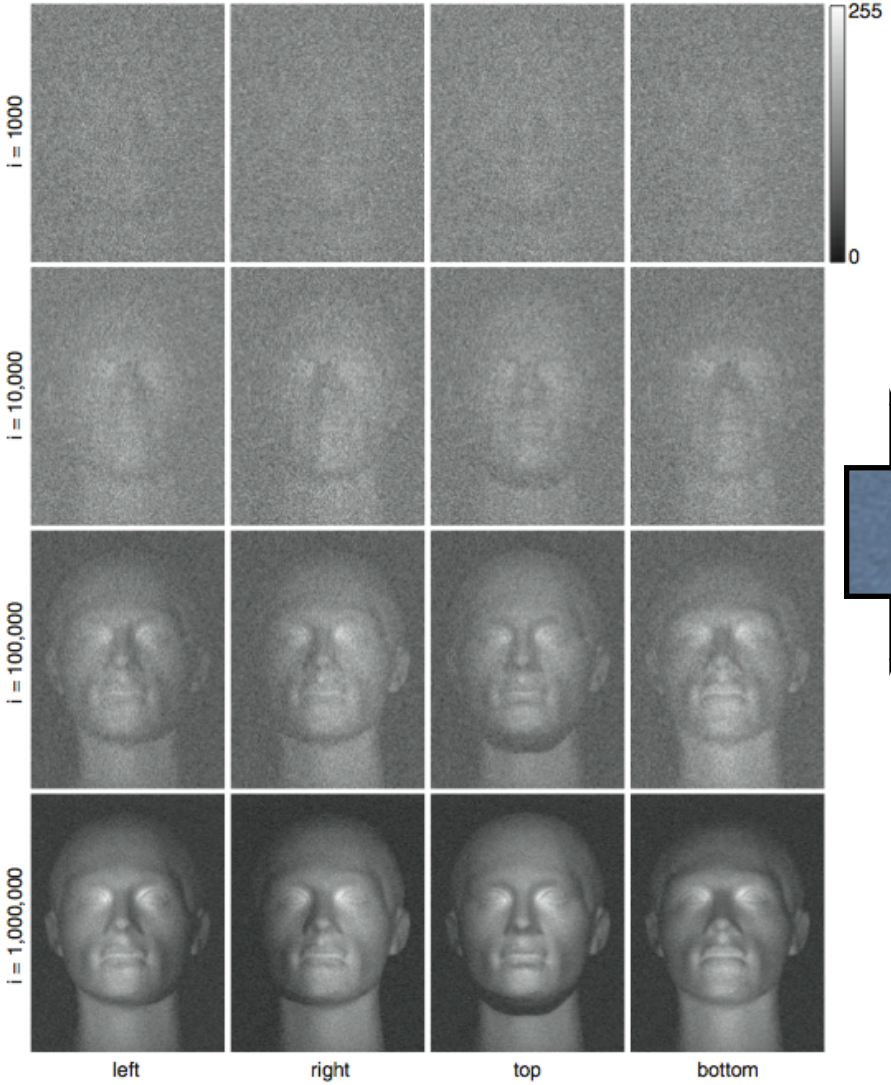
3D Ghost Imaging with classical light

Experimental setup for 3D computational ghost imaging



3D Ghost Imaging with classical light

Display random patterns at 660Hz

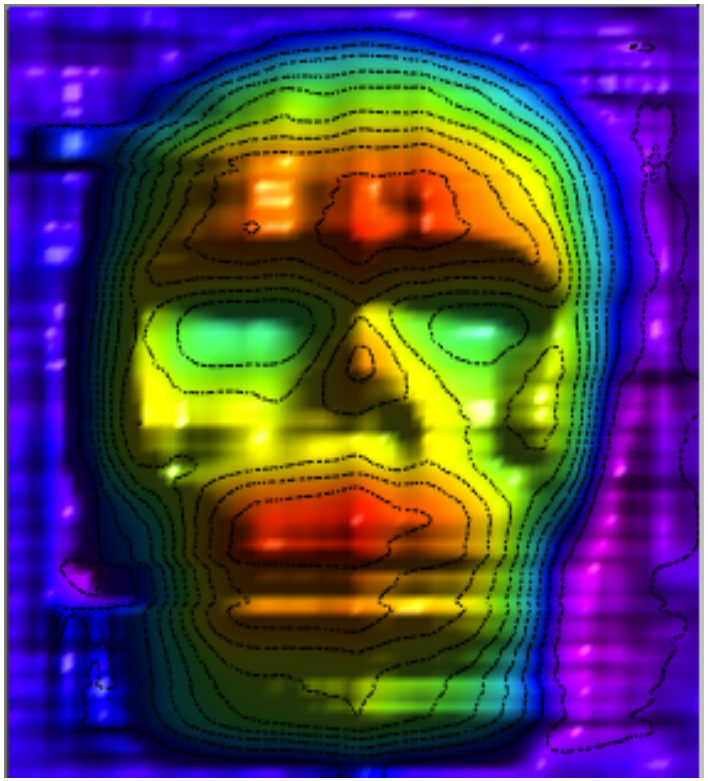


Surface Gradients

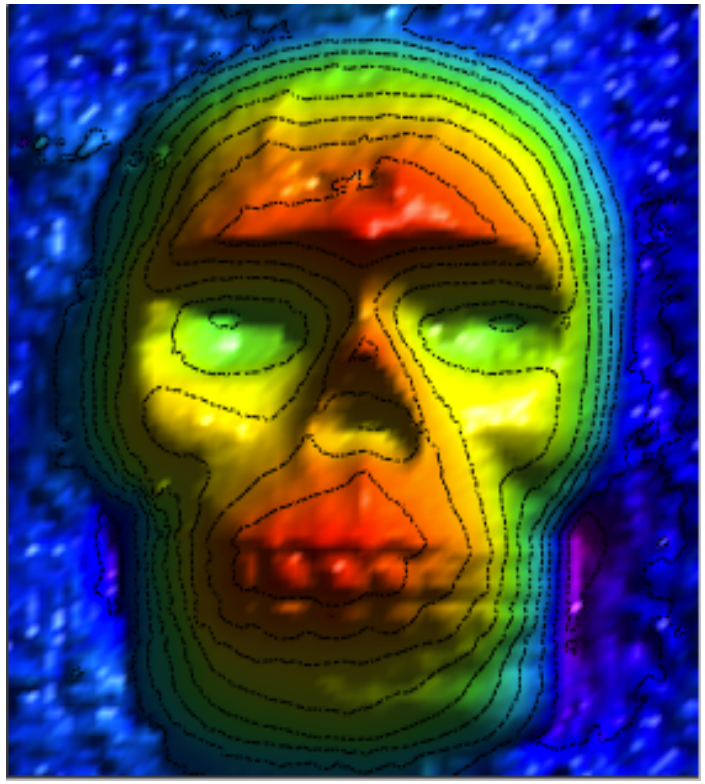
Integrate gradients (and optimise) to give surface profile

Calculating Surface height

Average over several possible boundary condition



Apply optimisation



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3D Computational Ghost Imaging

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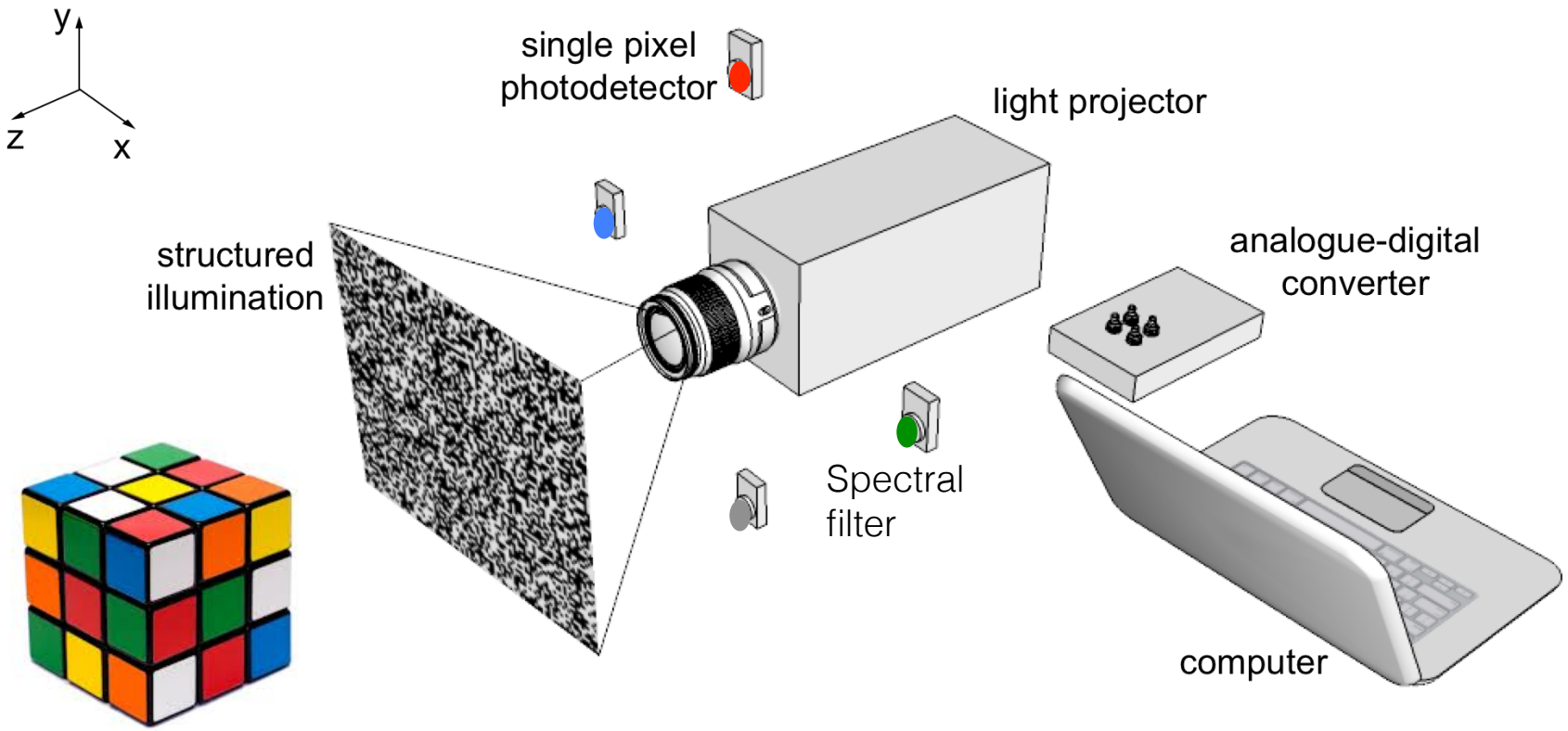
3D Computational Ghost Imaging

Colour Computational Ghost Imaging

Experimental setup for full colour and fluorescence computational ghost imaging



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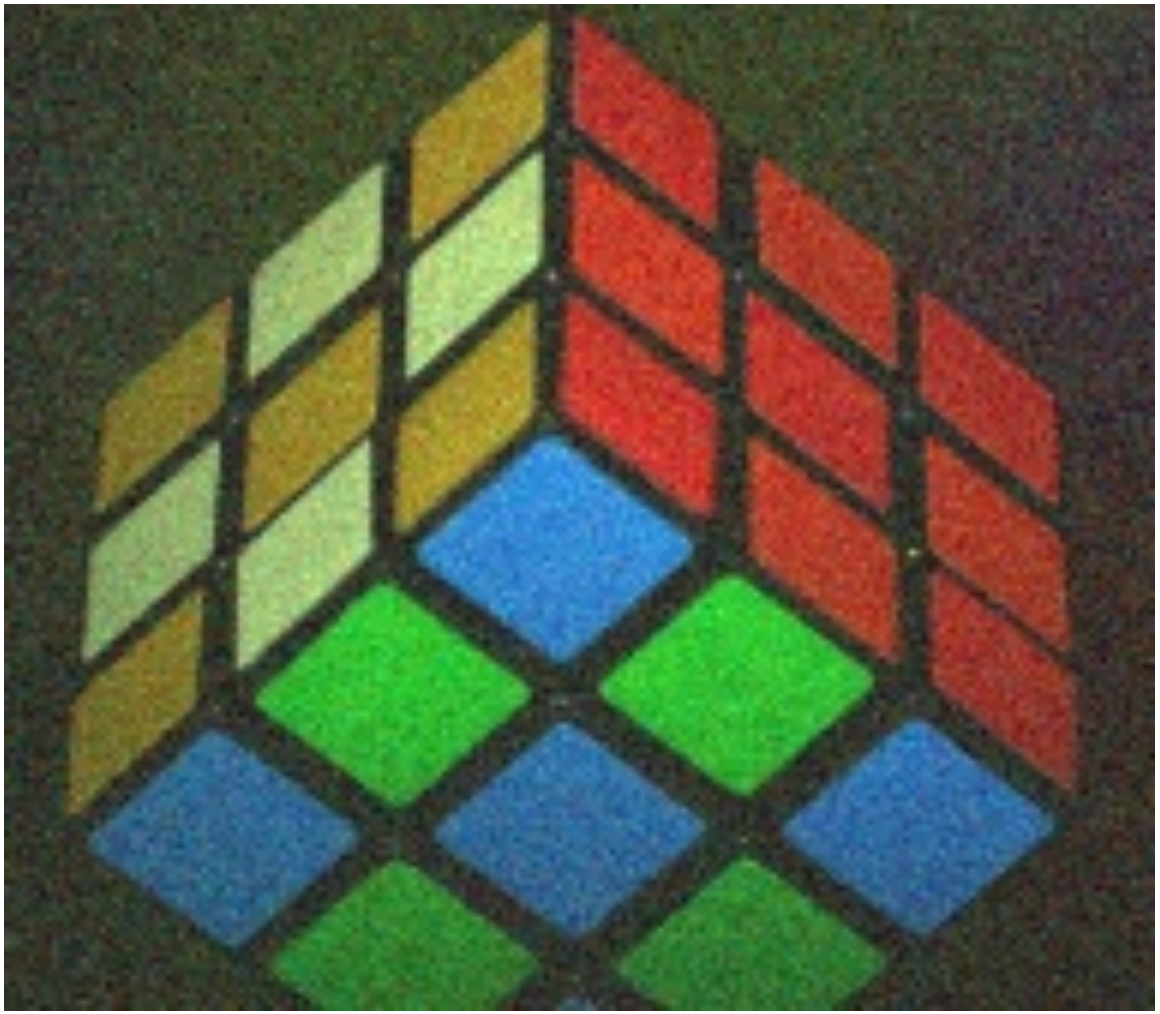
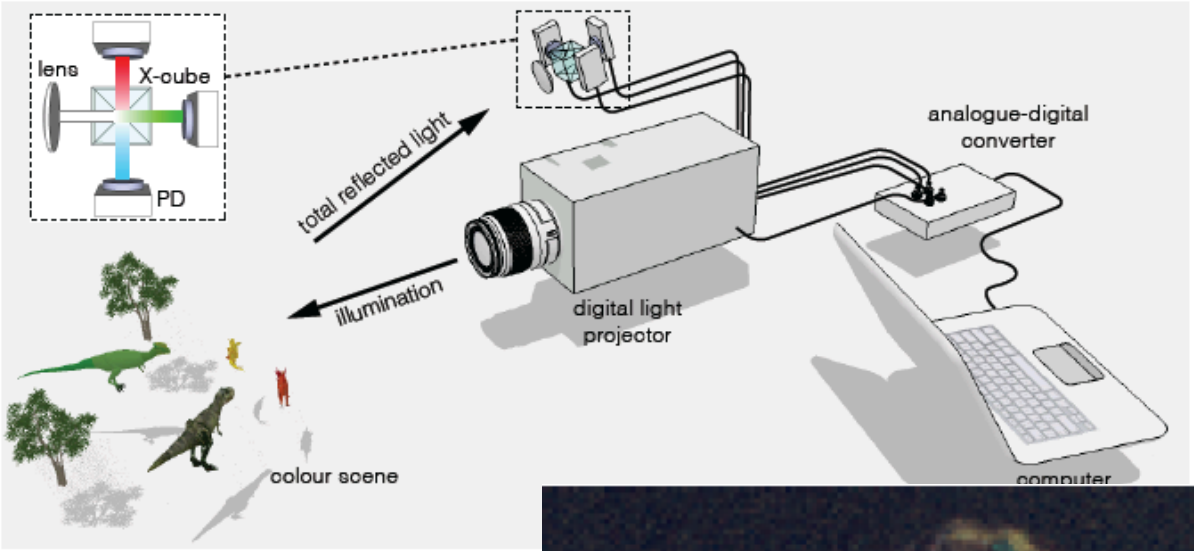
Colour Computational Ghost Imaging



Colour Computational Ghost Imaging



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Compressive Computational Ghost Imaging

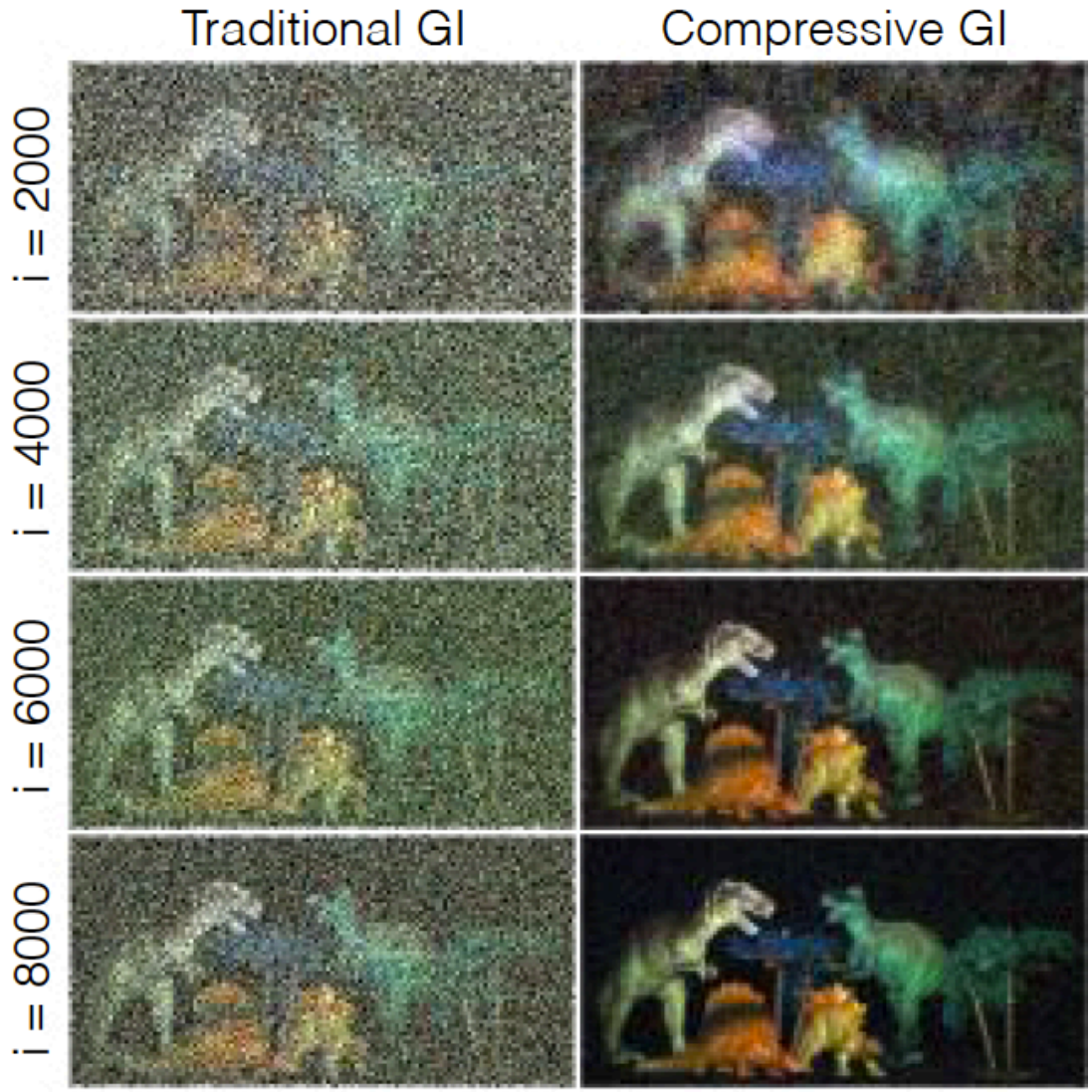

Image 12,000 pixels

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Before you ask

Is “random” the best choice of pattern (they’re not orthogonal nor are they “targeting” the right spatial frequencies
- no, but a few over constraints maybe not such a bad thing

Are there better algorithms for “inverting” the data
- yes, but maybe not as better as simulations free from “real-world” noise sources might suggest

Is this related to single pixel cameras
- yes, ≈ shape from shade with a single pixel camera

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Outline

Ghost Imaging (with entangled light)

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Computational Ghost Imaging ≈ Single Pixel Camera

Shape from Shade

3D Ghost Imaging

Ghost Imaging (with entangled light)

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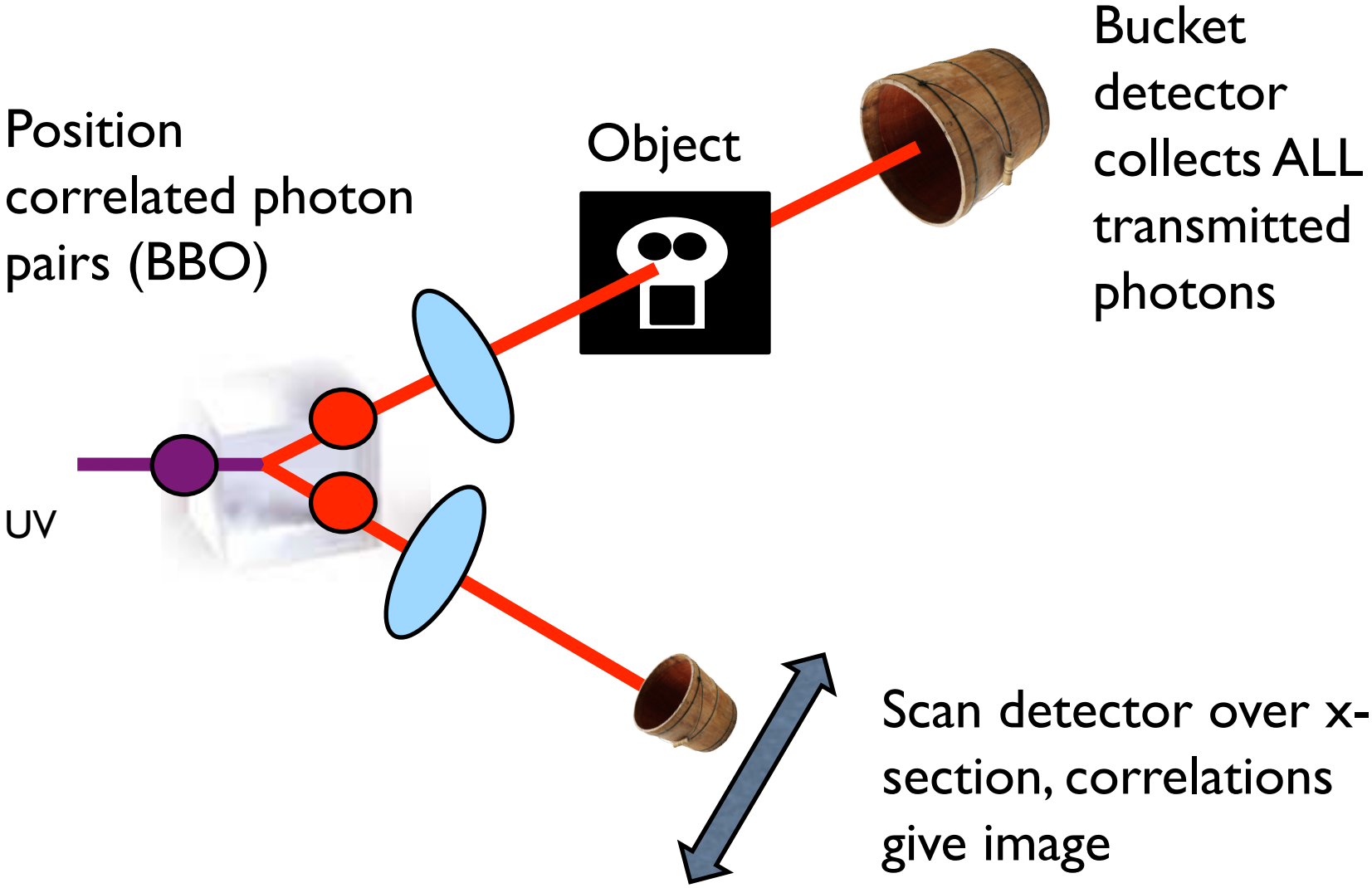
Quantum Ghost Imaging

Dr. Daniel Tasca

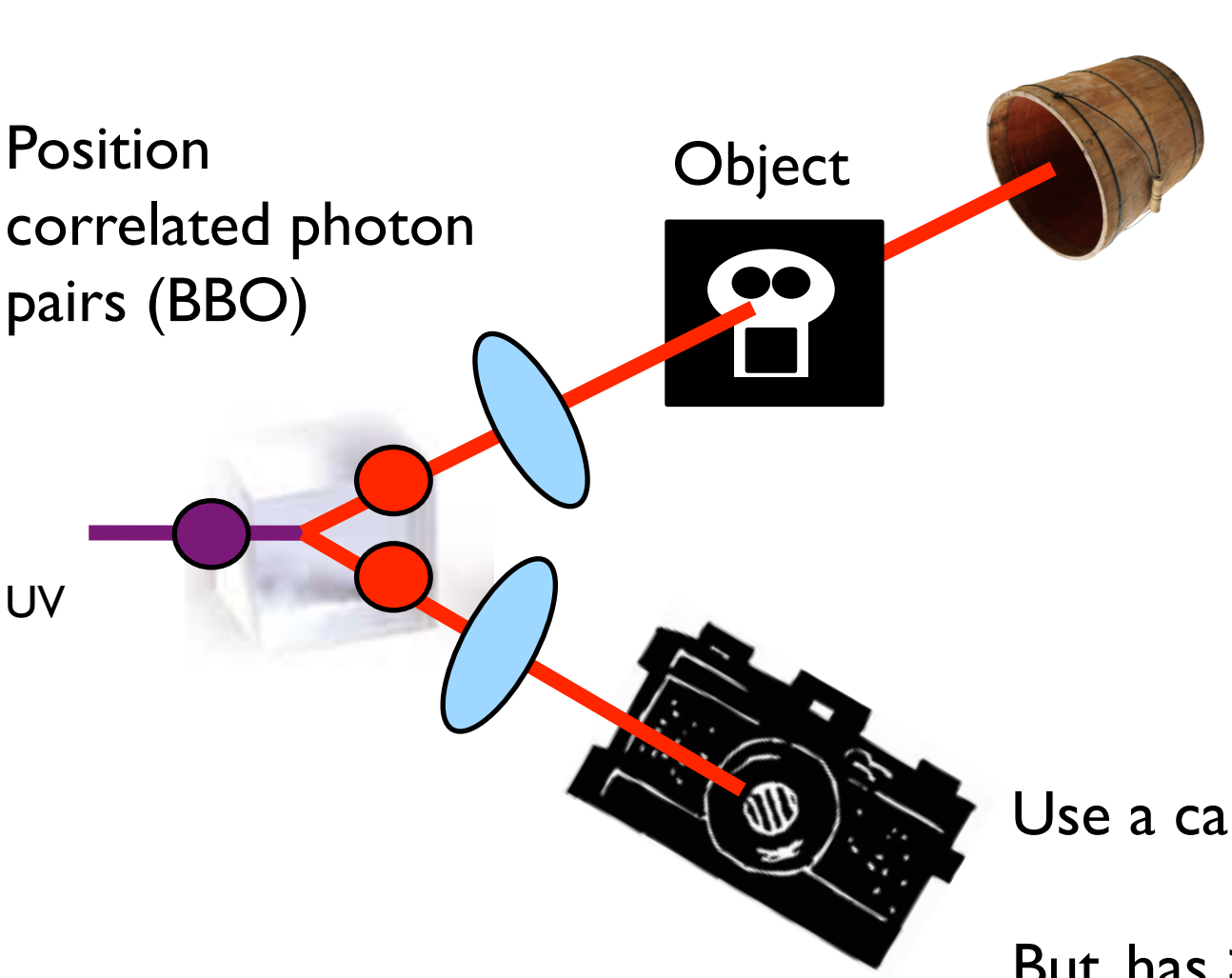
Mr. Reuben Aspden

Prof. Bob Boyd

Ghost imaging with (quantum) correlated light



Ghost imaging with (quantum) correlated light



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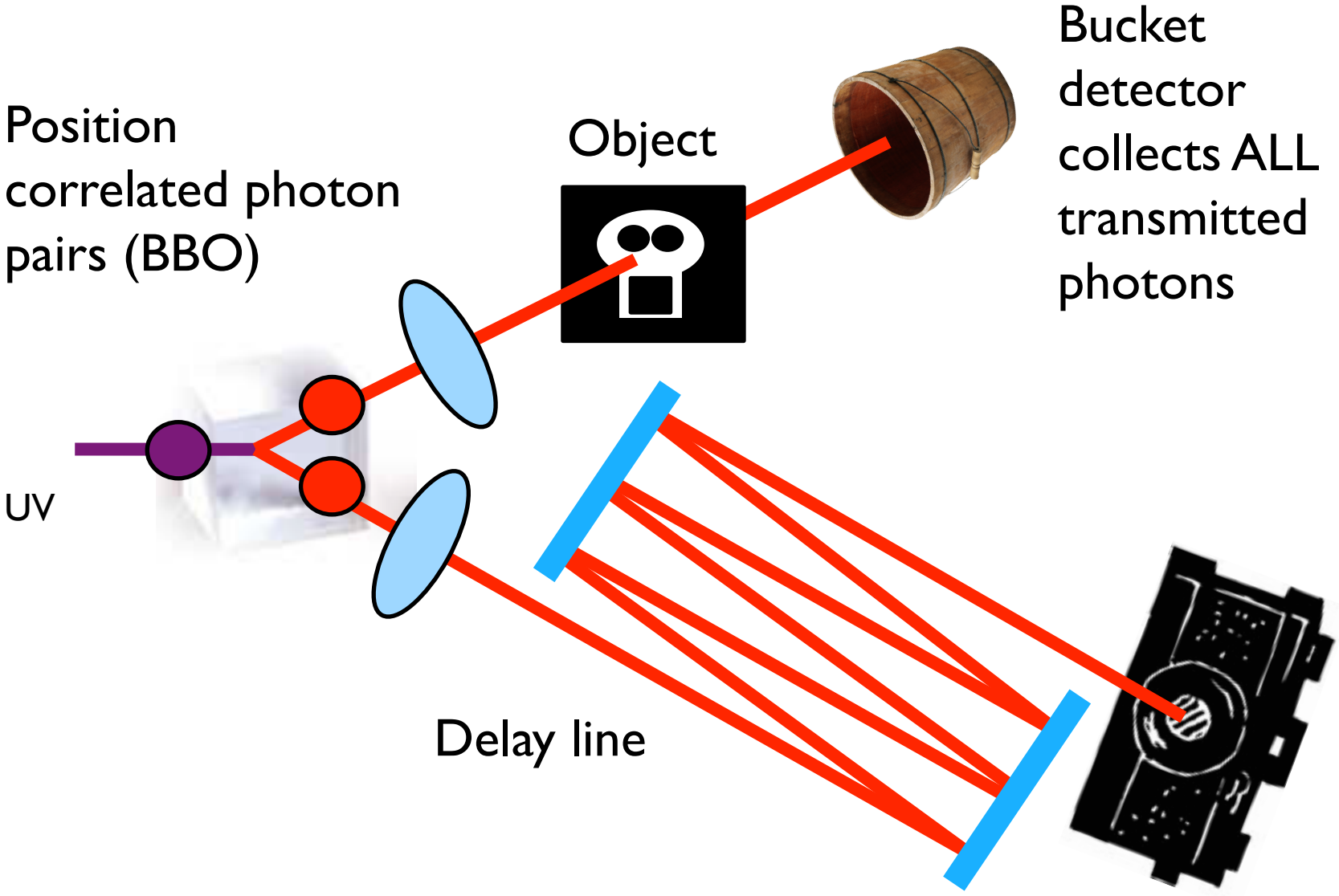
Ghost imaging with delayed correlated light



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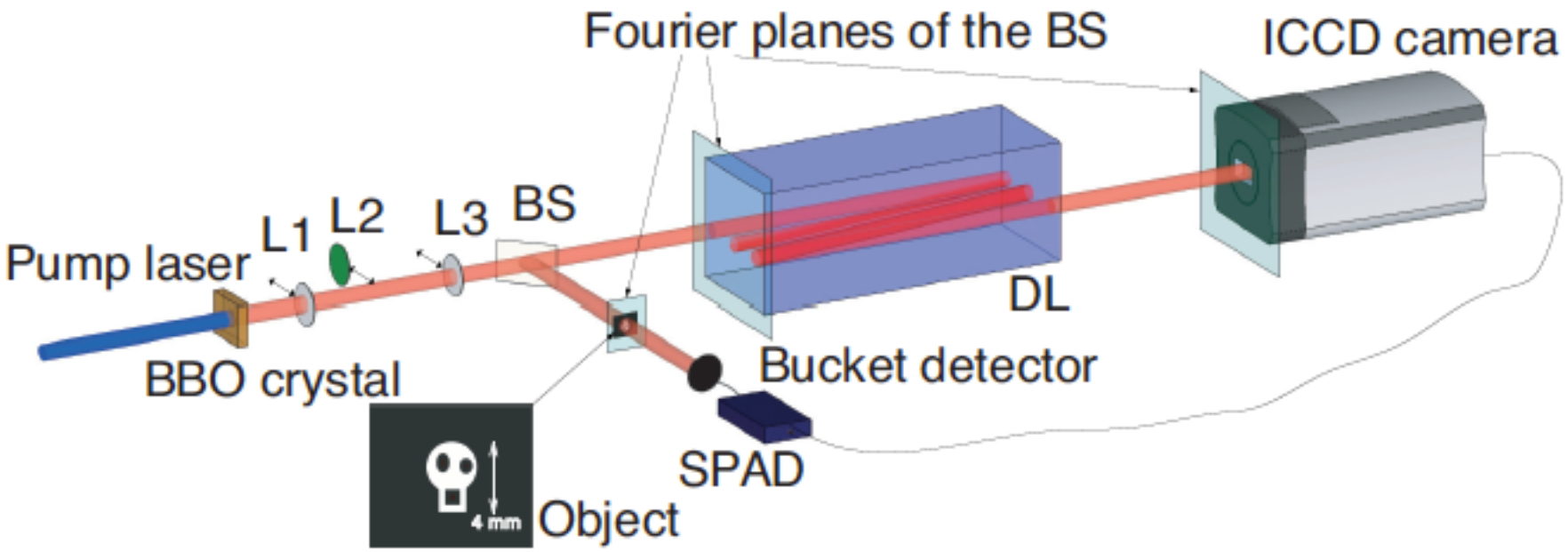
Ghost imaging with delayed correlated light



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Ghost imaging with (many) single photons

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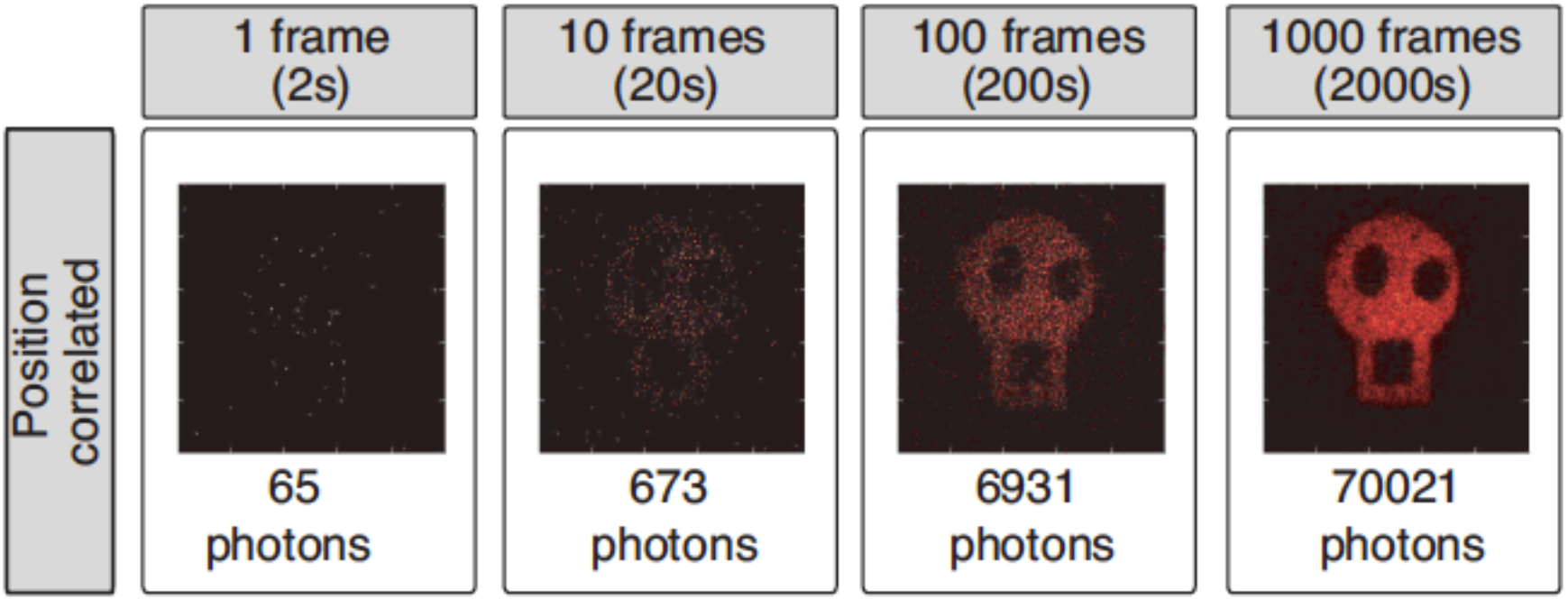
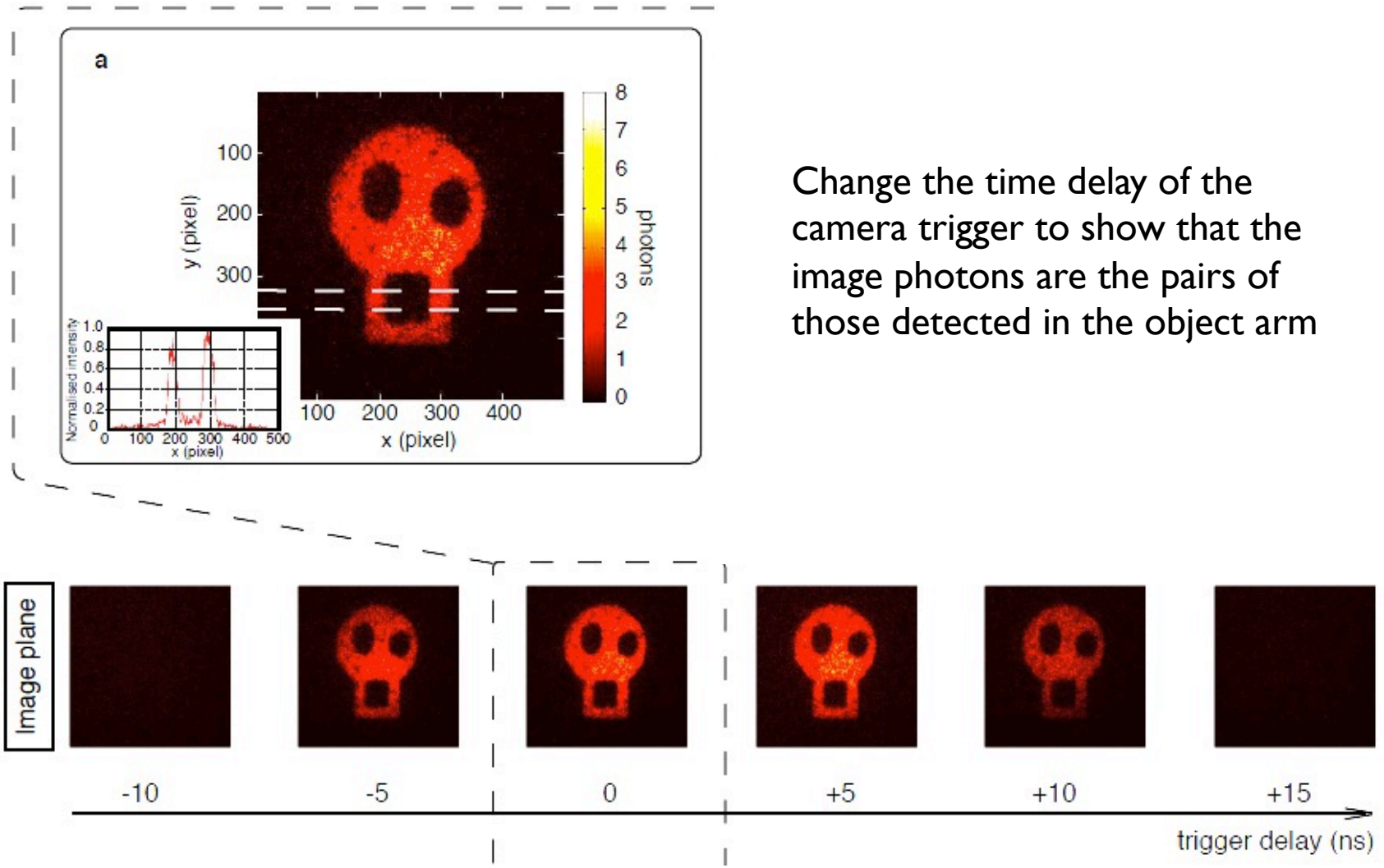
Ghost imaging with (many) single photons



Ghost imaging with gated single photons



Change the time delay of the camera trigger to show that the image photons are the pairs of those detected in the object arm

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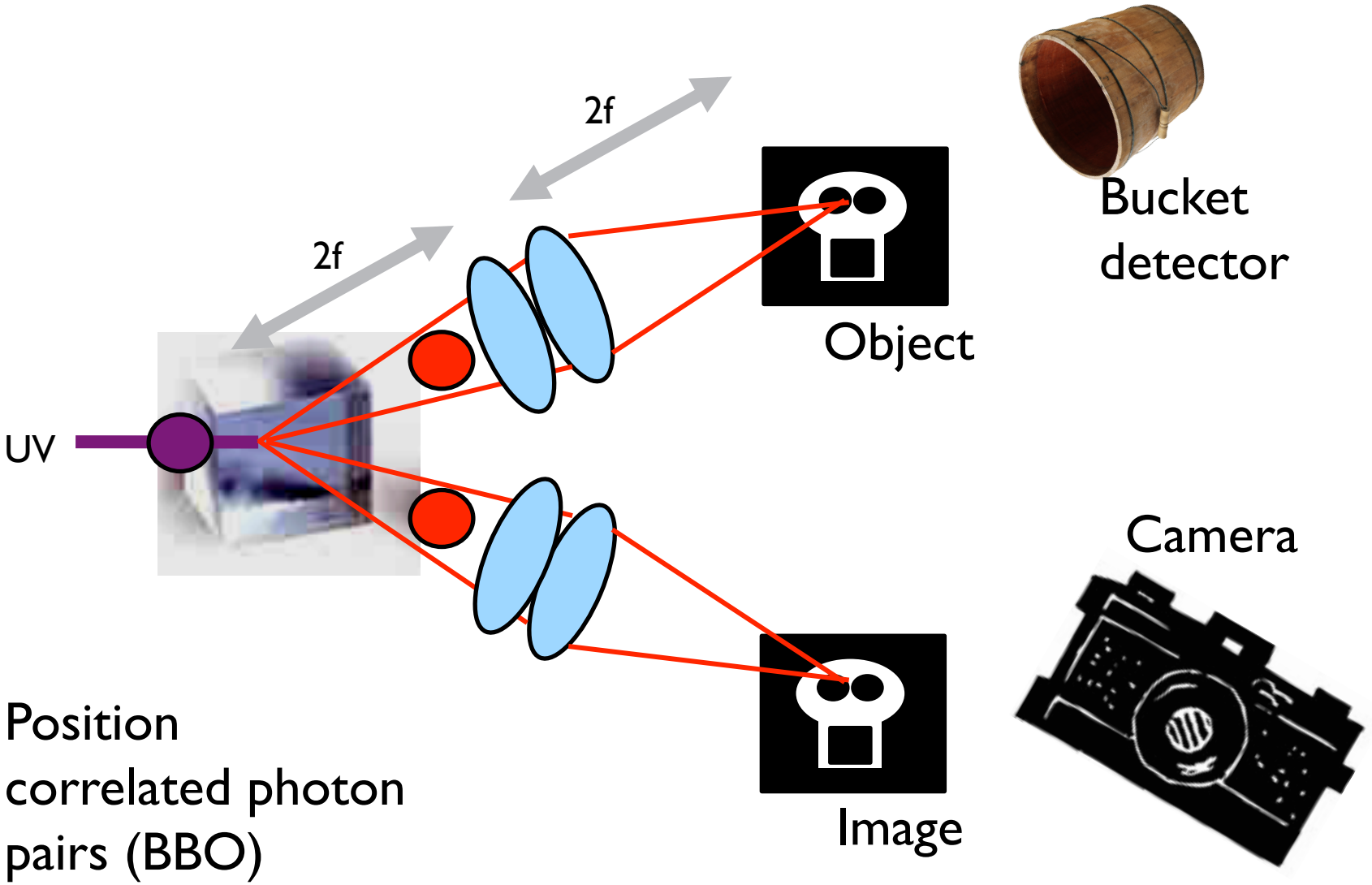
Ghost imaging with position correlated light



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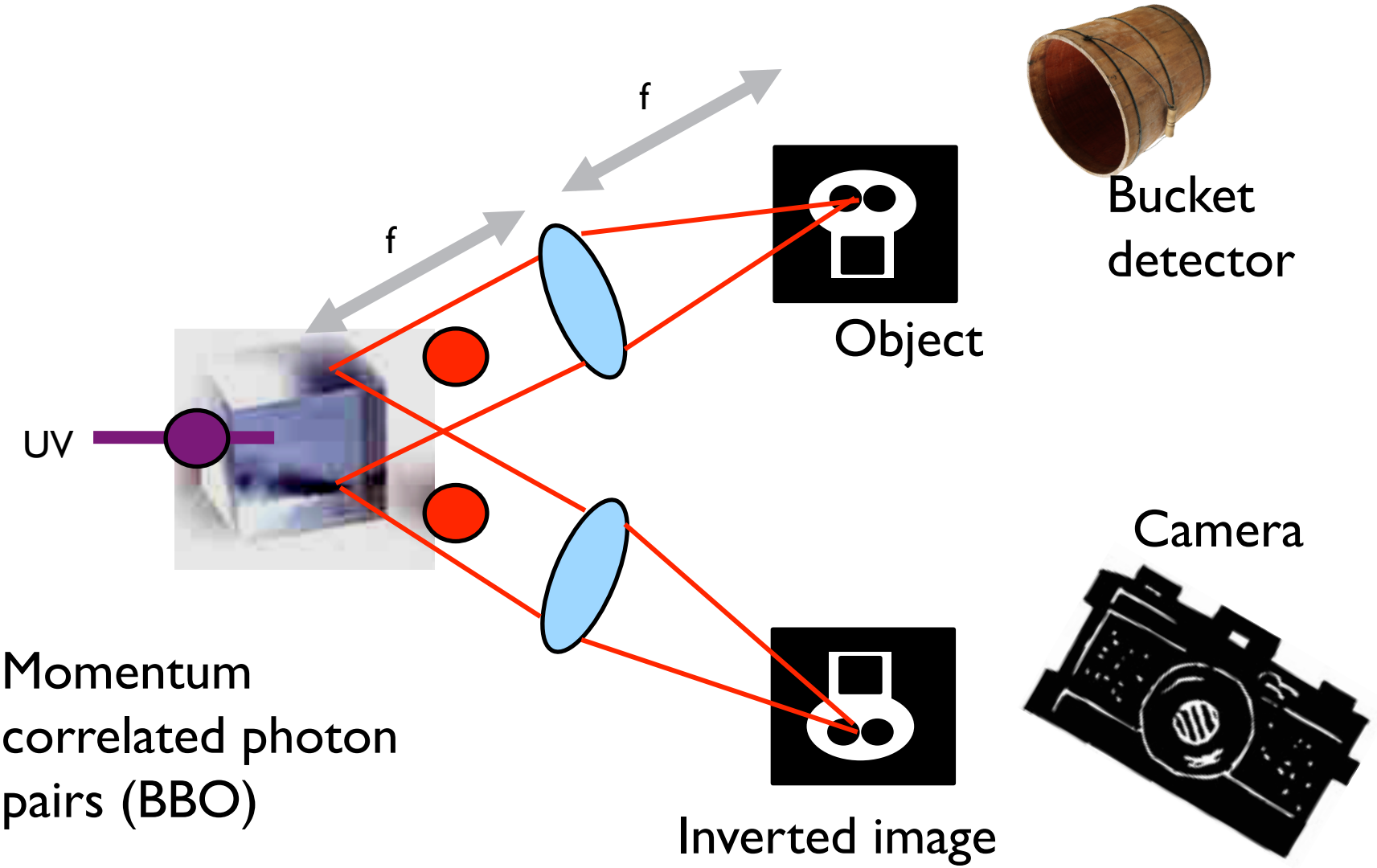
Ghost imaging with momentum correlated light



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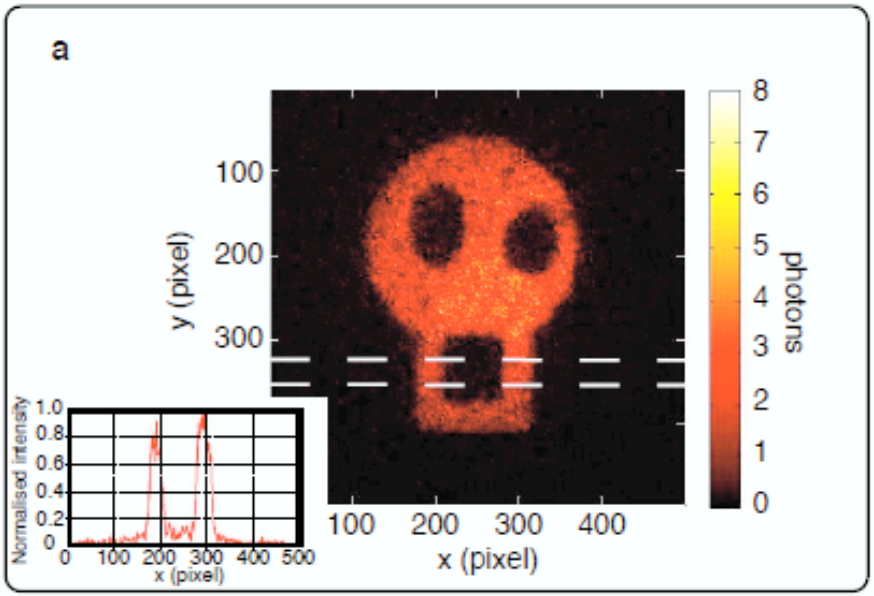
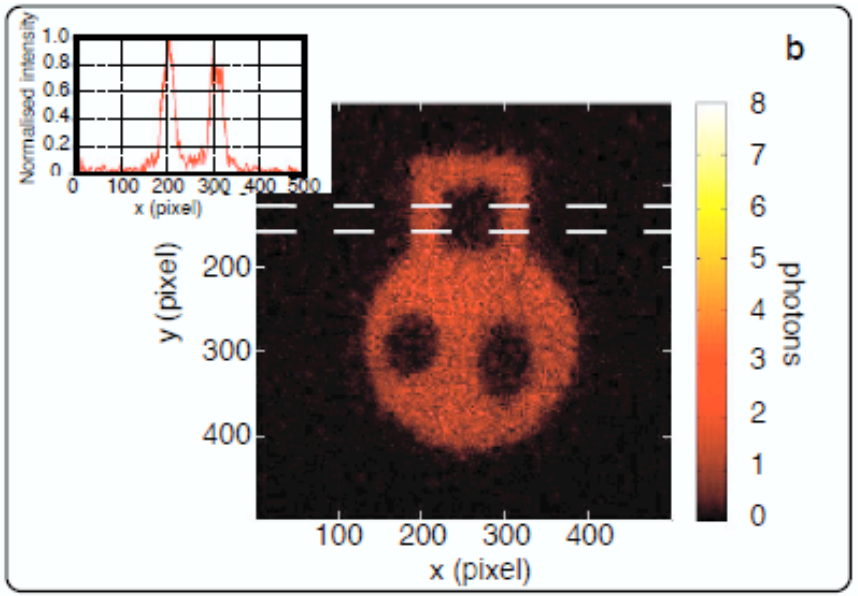
Ghost imaging with EPR correlations



POSITION correlation of down-converted photon pairs.



MOMENTUM correlation of down-converted photon pairs.

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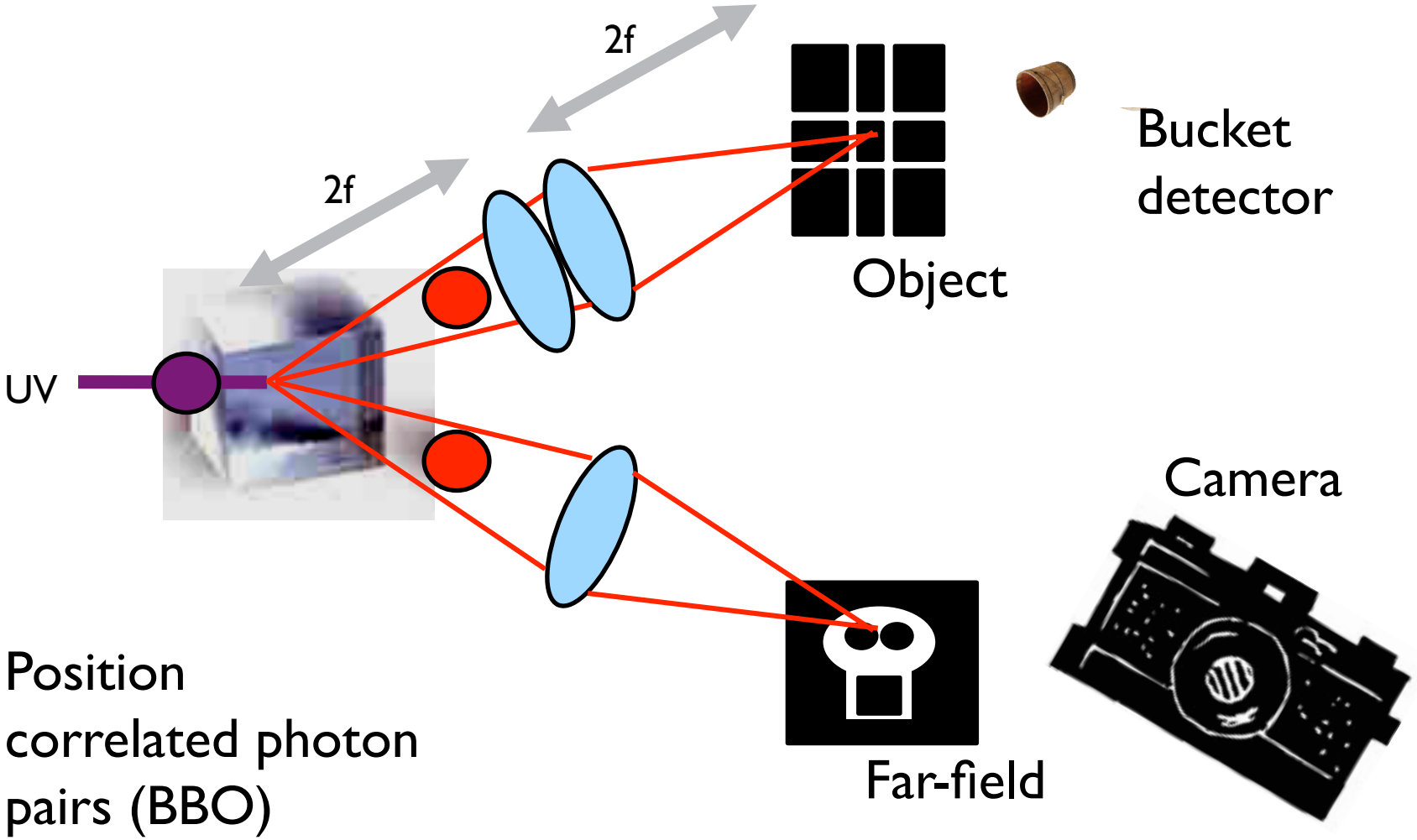
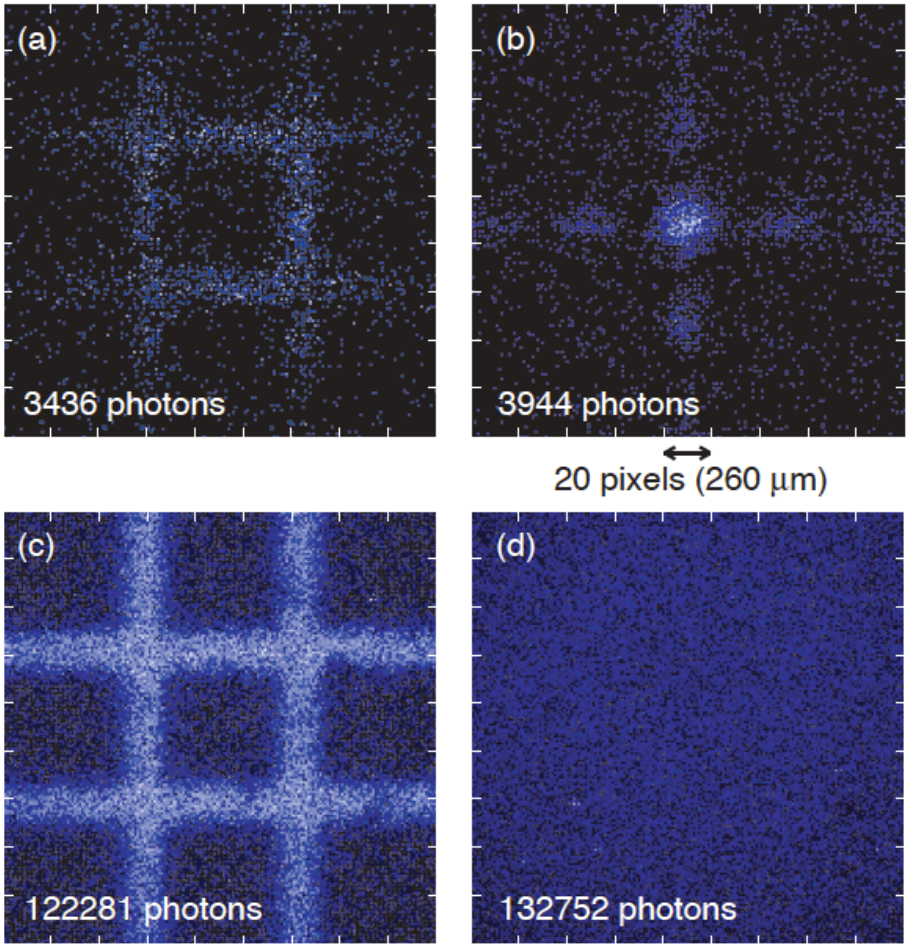
Ghost diffraction with position correlated light



Ghost diffraction with position correlated light



Single mode "bucket"

Multi mode "bucket"

Image plane

Far field

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Conclusions

Okay so neither classical nor quantum ghost imaging is magic but they are, never the less, quite cool…

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Thank you

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http://www.gla.ac.uk/schools/physics/research/groups/optics/

3D Computational Imaging with Single-Pixel Detectors

B. Sun,[1*] M. P. Edgar,[1] R. Bowman,[1,2] L. E. Vittert,[3] S. Welsh,[1] A. Bowman,[3] M. J. Padgett[1]

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