X-RAY GHOST IMAGING: LINE SCANS, RADIOGRAPHY AND TOMOGRAPHY

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Summary: We briefly describe the new field of x-ray ghost imaging, tracing it from first proofs-of-concept in 2016, through to the first application to ghost tomography in late 2018. In this method of imaging, only a small fraction of the x-rays pass through the object, yet all x-ray photons contribute to image formation. Avenues for reduced dose are a key driver for this exciting new tomographic field.

Ghost imaging is a new field of optics. Emerging from the field of quantum optics and initially believed to be underpinned by quantum-mechanical "spooky action at a distance", the field has rapidly achieved prominence in studies using classical visible light [1].

This form of imaging is utterly counter-intuitive. Indeed, the method often seems confusing, if not impossible, when first encountered. In ghost imaging, photons from a source pass through a speckle-making mask, leading to a spatially random pattern "A" being measured over the surface of a position-sensitive detector. A beam-splitter then removes a very small fraction of the photons, which pass through an object and are then recorded by a single-pixel "bucket" detector that merely records the total number "B" of photons falling upon it. This process is repeated for a number of different mask positions. While no photon that ever passes through the object is ever registered by a position-sensitive detector, and no photons measured by the position sensitive detector ever pass through the object, the *correlation* between A and B can be used to reconstruct the object [1].

Ghost imaging using x-rays was only very recently achieved, with the first proofs of concept for one-dimensional x-ray ghost imaging being published by Yu *et al.* [2] and Pelliccia *et al.* [3] in 2016. This was soon extended to x-ray ghost imaging of two-dimensional objects, by Zhang *et al.* [4] and Pelliccia *et al.* [5]. Finally, based on the theory and computer modelling of Kingston *et al.* [6], the first experimental realisation of ghost tomography (using potentially any form of radiation, not just x-rays) was reported by Kingston *et al.* [7] with x rays. The experimental setup was schematically identical to that in the figure below, using the process as described above, but with the additional feature that the sample was rotated to a number of different angular orientations.

We discuss the origins of ghost imaging, explain the key principles underpinning the method, review the current state of art in x-ray ghost imaging in 1D (line scans), 2D (radiography) and 3D (tomography), consider some key drivers such as the quest for ever-reduced dose, and speculate regarding future developments. We attempt to reduce the counter-intuitive nature of the method to a retrospectively obvious simplicity, and address the obvious question of: "Why would one want to perform tomographic imaging in this peculiar manner?"

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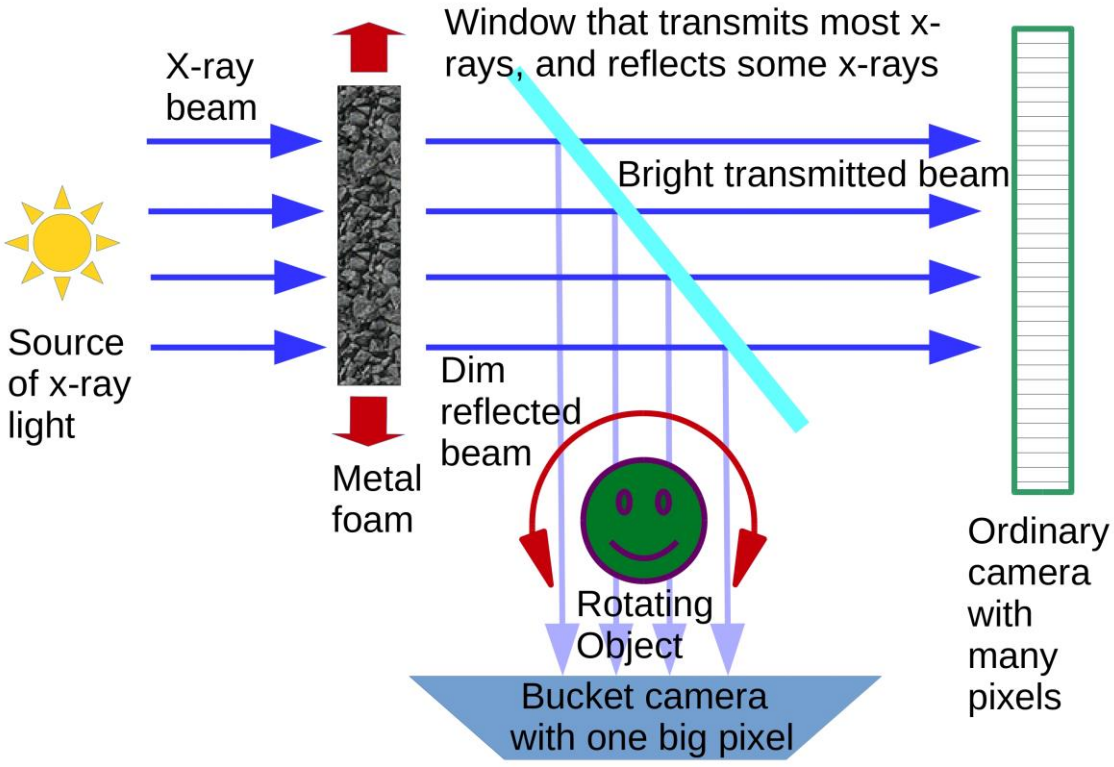

Figure: Generic experimental setup for ghost tomography