Quantum super-resolution in thermal light

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To circumvent Heisenberg's uncertainty principle, we multiplied the number of white-light photons using a dye, while calibrating the spontaneous photons. With larger wave-packets, the resolution is improved, as if with a larger aperture, but longer integration times are necessary.

Our experiment is based on amplification of photons for increased resolution. When a photon crosses the system's aperture, it reaches a light amplifier, which responds by stimulating the emission of many additional photons. These stimulated photons are correlated with the original photon, both in direction and in wavelength. These daughter photons have lesser uncertainty than their diffraction limit, and by their mere number they allow for a better measurement of the angle at which the original photon has passed the telescope aperture [1-3]. This is an improvement on direct detection, which is based only on the original photon.

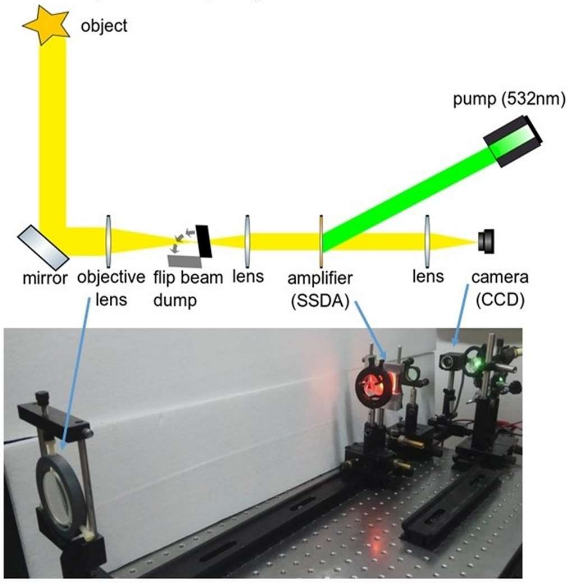

Fig. 1. The telescope objective collects the light from a remote lab object, followed by a chopper (not pictured), relayed into a wide-band solid-state dye amplifier, and focused into a camera.

Unfortunately, the stimulated emission is also accompanied by constant spontaneous emission. The copious spontaneous photons are emitted in all directions, unlike the stimulated ones, creating a bright background, and reducing the achieved increase in resolution. As a result, we had to separately measure also the spontaneous photons. In the lab experiment (Figs. 1, 2) we blocked the light source, thus measuring only the spontaneous light half the time, while the rest of the time served to measure both stimulated and spontaneous photons. Subtraction of the background image from the combined image left only the clean image of the source. This is the first time such an experiment was performed with white light [4], since most light amplifiers tend to be monochromatic.

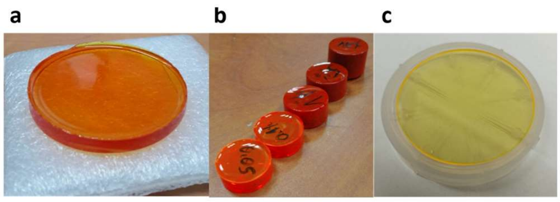

Fig. 2: Solid state die amplifiers. (a) DCM:PMMA; (b) DCM:CR7; (c) Glass spin-coated with PMN:PMMA. All samples are about 5 cm in diameter.

We measured the radial contrast in a pinwheel target (as equivalent to the MTF). Two different dye amplifiers produced 19% and 38% resolution improvements (Fig. 3). No use was made of prior knowledge of the object shape.

The increased resolution comes at the price of lower sensitivity, a worthy price to pay. Moreover, the loss of sensitivity can be overcome partially by increasing the exposure time, or the observation period.

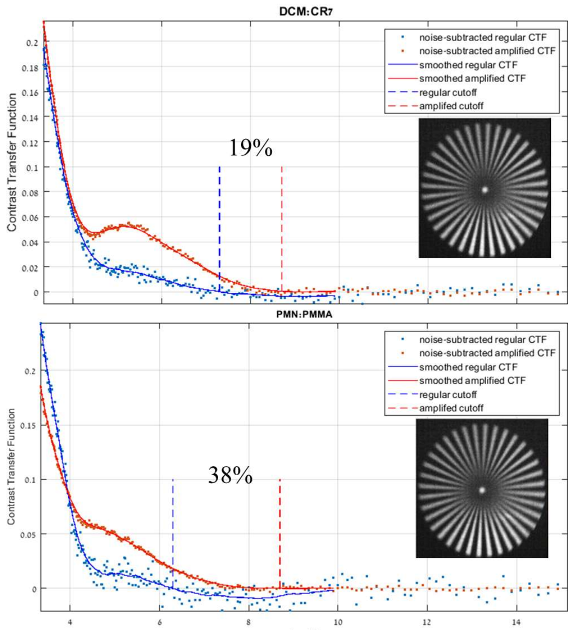

Fig. 3: Reconstructed Contrast Transfer Functions for regular and amplification imaging using DCM:CR7 and PMN:PMMA dyes. The curves show the smoothed CTF values. The zero CTF is set according to the mean noise beyond the cut-off, as marked by the vertical broken lines.

References

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