# Diffraction-free and self-healing light droplets for deep volume imaging

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An ideal direct imaging system entails a method to illuminate on command a single diffraction-limited spot in a generally thick and turbid volume. The best approximation to this is the use of large-aperture lenses that focus light into a spot. This strategy fails for regions that are embedded deep into the sample, where diffraction and scattering prevail. Bessel beams [1] and Airy beams [2] are solutions of the Helmholtz Equation that are both non-diffracting and self-healing, features that make them naturally able to outdo the effects of distance into the volume but intrinsically do not allow resolution along the propagation axis.

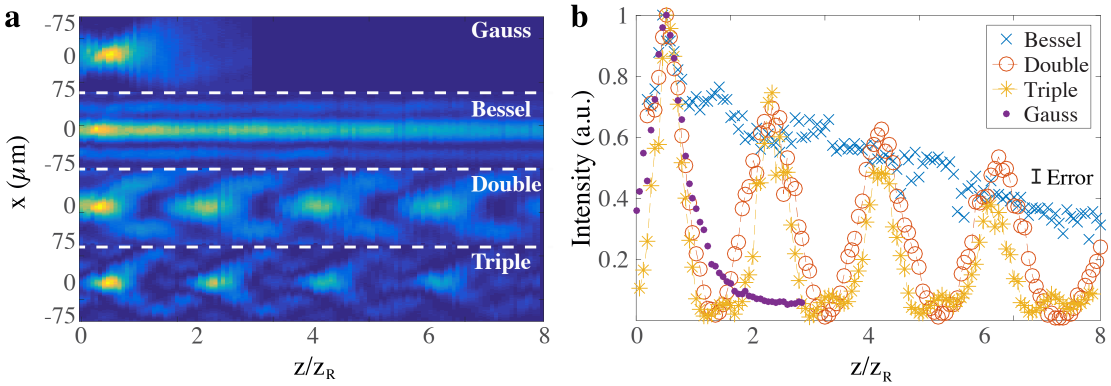


Figure 1. Top view (a) and axial intensity profile (b) of a Gaussian beam, a Bessel beam and light droplets obtained with a double and a triple annular mask respectively. Whereas the Gaussian beam diverges after the lens focus, both Bessel beam and light droplets are shown to be non-diffracting even after ten Rayleigh lengths ($Z_R$).

In this work, we demonstrate diffraction-free self-healing three-dimensional monochromatic light spots able to penetrate deep into the volume of a sample, resist against deflection in turbid environments, and offer axial resolution comparable to that of Gaussian beams [3]. The fields, formed from coherent mixtures of Bessel beams, manifest a more than ten-fold increase in their undistorted penetration, even in turbid milk solutions, compared to diffraction-limited beams. In a fluorescence imaging scheme, we find a ten-fold increase in image contrast compared to diffraction-limited illuminations, and a constant axial resolution even after four Rayleigh lengths. Results pave the way to new opportunities in three-dimensional microscopy.

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[2] Siviloglou, G. A., Broky, J., Dogariu, A., & Christodoulides, D. N. Observation of accelerating Airy beams. Phys. Rev. Lett., 99(21), 213901 (2007).
[3] Antonacci G., Di Domenico G., Silvestri S., DelRe E. & Ruocco G., Diffraction-free light droplets for axially-resolved volume imaging, *Sci. Reports* **7,** 41598 (2017).