INVESTIGATIONS TO THE USE OF GAUSS-LAGUERRE BEAMS WITH *N* OBJECTIVE LENSES IN CONFOCAL MICROSCOPY

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1 INTRODUCTION

The 4Pi confocal microscope was proposed in 1992 in an European patent application by Hell suggesting the use of more than a single microscope objective lens to form an image with enhanced spatial frequency pass-band. Shortly after this in 1994 Stelzer proposed the use of two and three microscope objective lenses in a 90° configuration. This set-up had the advantage to produce a virtually spherical effective point spread function (PSF). In 2001 Haeberlé proposed the use of six objective lenses in confocal microscopy which had the effect of further symmetrising the effective PSF with the added benefit of also reducing its volume.

The use of radially and azimuthally polarised beams has been studied by many researchers. However, what previous studies did not point out is the fact that Gauss-Laguerre beams form a complete set of orthonormal functions and consequently any function in the same co-ordinate system may be expanded as a weighted sum of these. Hence, the use of coherently and/or incoherently added Gauss-Laguerre beams, arriving at different directions at the focal volume, as the effective PSF provides an interesting subject to study. Our presentation is concerned with this problem.

2. THE MODEL

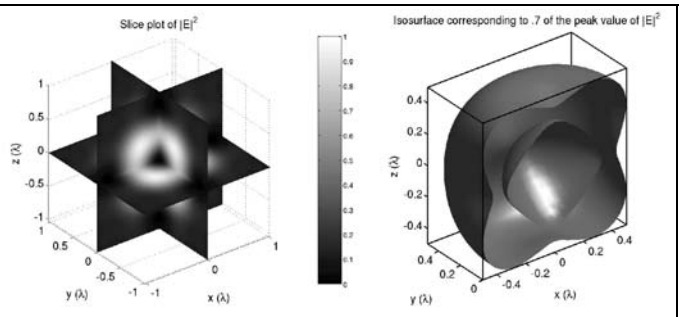

Fig 1: Gray scale and isosurface plots of a hollow sphere used to generate a STED emission volume

We have developed a high aperture vectorial model to simulate the image formation of a compound confocal microscope using *N* objective lenses. Each of these lenses is illuminated by any combination of Gauss-Laguerre beams.

To illustrate the potential of the method we present Figure 1. We used three azimuthally polarised beams, one in the direction of incident illumination and two mutually orthogonal to that, to reduce the effective excitation volume in e.g. a STED type system. We emphasise that the isosurface in Fig. 1 shows a spherical generation volume (i.e. PSF) of 0.4λ in diameter but this corresponds to 70% of the peak power. In STED microscopy one can choose to saturate the beam power almost at will so the effective PSF of the STED microscope could readily be reduced even further.

In addition to the use of our method in STED microscopy, the multiple objective system is useful for a variety of other problems, such a tomography or PSF manipulation including polarisation engineering.