# COMPUTATIONAL TECHNIQUE FOR RESOLUTION LIMIT OF LASER MICROSCOPY WITH THE USE OF FEYNMAN DIAGRAMS

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Recently, many kinds of laser microscopy have been developed by using a variety of optical processes. Although Abbe's definition of resolution limit is still used as the standard, it is relatively unknown that the $2NA/\lambda$-limit can be applied only to the microscopy utilizing $\chi^{(1)}$-derived optical process, such as linear absorption, transmission, and reflection, where $\chi^{(1)}$ is the electric susceptibility. If higher order $\chi^{(i)}$-derived optical processes ($i \geqq 2$) are exploited, the resolution limit may surpass $2NA/\lambda$ and the missing cone can be overcome, where $\chi^{(i)}$ is the nonlinear susceptibility. In this research, we formulate the framework that connects double-sided Feynman diagrams to the resolution limit of all laser microscopy.

All of linear, nonlinear, coherent, and incoherent optical processes can be described by the Feynman diagram that includes some arrows (electric field) as shown in Fig 1. In our microscopy model, $P_{\mathrm{ex}}(\boldsymbol{f})$ and $P_{\mathrm{col}}(\boldsymbol{f})$ represent 3-D pupil functions of excitation and signal-collection systems, respectively. We show that each arrow corresponds to the 3-D pupil function, following the rule we derived. To compare the optical resolutions of all types of microscopy, we define "3-D apertures" in spatial-frequency domain, from which optical transfer functions (OTF) are calculated in cases where OTF can be defined. The 3-D aperture, which means the contribution rate of Fourier components in object to the image formation, can be computed by connecting all 3-D pupil functions in a diagram with convolution.

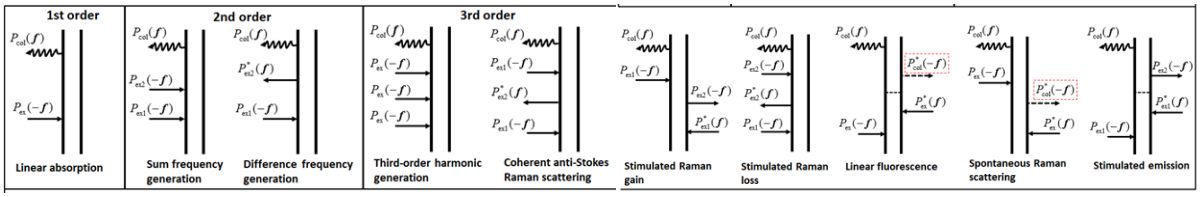


Fig. 1. Diagrams for some optical processes. Solid, dotted, and wavy arrows denote excitation, vacuum, and signal field.

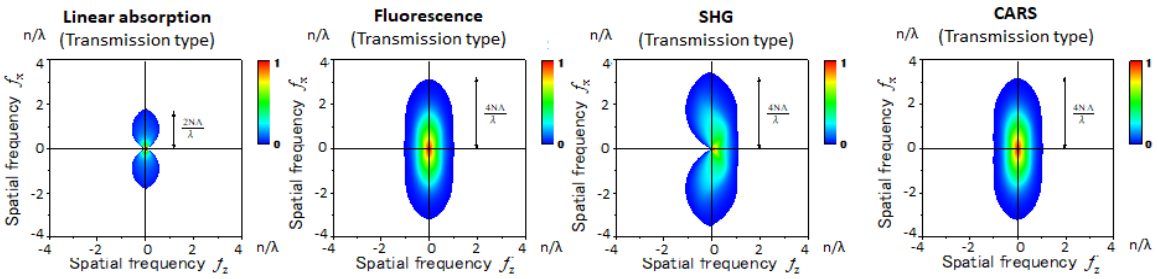


Fig. 2. 3-D apertures for some kinds of microscopy. NA is 1.2 (water immersion). $\lambda$ is excitation wavelength.

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