Symmetries and Selection Rules in Nonlinear Wave Mixing with Structured Light

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We investigate nonlinear wave mixing processes induced by transversely structured light beams. The interplay between different photonic degrees of freedom determines the structure of the fields generated by the nonlinear processes. In birefringent media, the nonlinear interaction can be directly affected by the polarization of the interacting beams. For example, in Type-II second harmonic generation, this interplay allows for polarization-controlled switching between different orbital angular momentum (OAM) operations. It can also be used for spin-to-orbital angular momentum transfer, as shown in Fig. 1. Moreover, either in birefringent or isotropic media, a less intuitive interplay occurs between radial and angular degrees of freedom of paraxial modes undergoing nonlinear propagation. This radial-angular coupling leads to interesting chiral relationships that will be discussed.

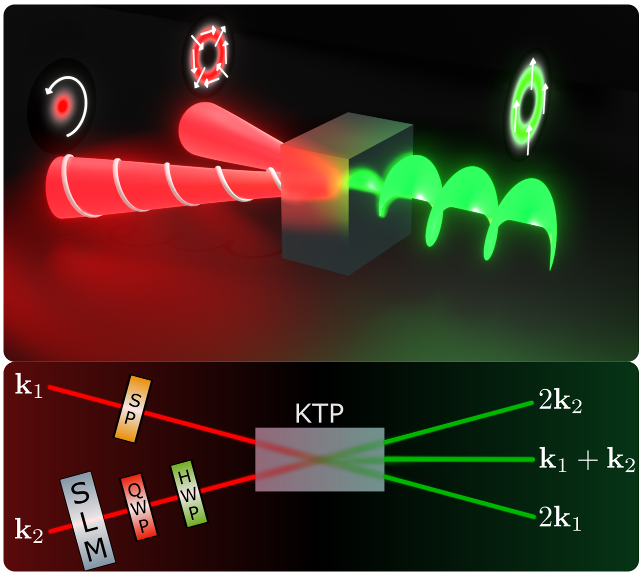

Figure 1: Scheme for spin-to-orbital angular momentum transfer in nonlinear wave mixing

Under paraxial propagation, the nonlinear interaction can be investigated using a transverse mode decomposition. Depending on the symmetry properties of the nonlinear medium, one can use either Laguerre- or Hermite-Gaussian modes to describe the nonlinear interaction. The mode coupling is governed by the spatial overlap between the interacting modes, which dictates the transverse properties of the fields generated by the process. While OAM conservation is a natural consequence of the spatial overlap, the generation of radial modes in the nonlinear interaction is a less intuitive outcome that can be understood as a result from the cross modulation of the interacting beams.

When the nonlinear interaction is driven by optical modes contained in the orbital angular momentum Poincaré sphere, the simultaneous constraints imposed by OAM conservation and maximal intensity overlap create an interesting Poincaré sphere symmetry between the interacting modes. This symmetry will be discussed both in three- and four-wave mixing processes. We show that under usual assumptions, the output fields can be described by modes belonging to Poincaré spheres, and that the angles describing the input and output modes are related according to well-defined rules.