Gamma-ray vortices emitted from nonlinear inverse Thomson scattering of circularly polarized light

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Abstract: We have proposed a new method to generate gamma-ray vortices using nonlinear inverse Thomson scattering. Inverse Thomson scattering is a radiation process by which a high energy electron converts a low energy laser photon to high energy one. When the peak power of a laser is sufficiently intense, a nonlinear effect of inverse Thomson scattering occurs and higher harmonic photons are emitted. We theoretically showed that higher harmonic gamma-rays formed helical wavefronts and carried orbital angular momentum.

After remarkable work conducted by L. Allen et al., which revealed that a Laguerre Gaussian (LG) laser mode carries orbital angular momentum (OAM) [1], research on optical vortices using visible wavelength lasers has thrived and resulted in successful applications in various research fields. Moreover, vortex beams are not limited to visible light but have been generated in ~10 keV X-rays, terahertz/radio waves, sub-MeV electron beams and cold neutrons. Recent theoretical works show that optical vortices at ultraviolet, X-ray, and MeV gamma-ray frequencies likely trigger new phenomena in photoionization [2], a dichroic effect [3], Thomson and Compton scattering [4], photodisintegration [5], and nuclear excitation [6].

We have theoretically demonstrated that gamma-ray vortices are produced by nonlinear inverse Thomson scattering (NITS) [7]. ITS is a fundamental radiation process, which a high energy photon is produced by the interaction between a relativistic electron and a low energy photon. When an electron interacts with an intense laser field, the nonlinear effect of ITS becomes prominent and higher harmonic photons are emitted in addition to the fundamental radiation. We theoretically revealed that an electron inside a laser field obeys a circular motion and the electric fields emitted by NITS using a circularly polarized laser possessed the phase term of $\exp\{i(n-1)\phi\}$, where n is the harmonic number and ϕ is the azimuthal angle. This means that the higher harmonic photons carry OAM equal to $(n-1)\hbar$, where $\hbar$ is the Planck constant divided by 2π. In contrast to a previous work [8], gamma-ray vortices are produced by the interaction between an electron and a plane wave laser. Our work well explains a recent experimental result regarding NITS that clearly shows an annular intensity distribution of the second harmonic X-rays as a remarkable feature of a vortex beam [9]. Moreover, we developed a classical theory of NITS of a two-wavelength circularly polarized laser beam [10]. We revealed that an electron inside a two-wavelength laser field underwent a cycloid motion and a combination of two wavelengths differing by one order of magnitude or more was advantageous for producing gamma rays carrying a large OAM of $\sim 10\hbar$.

NITS has been discussed as a candidate for radiation processes in astrophysical environments. Intense electromagnetic waves are thought to exist near pulsars and may be emitted during gamma-ray bursts. In such environments, high-energy photons carrying OAM would be produced via NITS [11].

In this conference, we will present details of theoretical calculation and a plan of the experimental demonstration.

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