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Photon Vortex Generation and Photonuclear Reactions by Photon Vortex in Astronomical System

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Photon vortices are light that carry large orbital angular momentum (OAM) in quantum level [1]. They can be described by Laguerre-Gaussian or Bessel wavefunctions, which are waves being the eigenstates of the distinct angular momentum along their propagation direction . Unlike plane-wave photons, photon vortices interact differently with materials because their OAM changes the process where they transfer the relatively large angular momentum. In gamma-ray bursts (GRBs), photons in the keV range can become highly polarized due to strong magnetic fields.

Photon vortices can change the total angular momenta of compound nuclei transferred from the photon vortices when they interact with them. This is thought to play an important role in nucleosynthesis in the Universe. Liu et al. [2] found that the amplitudes of low multipole giant resonances become weaker when a photon vortex interacts on a nucleus with a relatively small impact parameter.

We study the process that photon vortices form when electrons have spiral motion in magnetic fields as strong as 10^{12}-10^{13} G. Our study includes effects from Landau quantization. Our results show that these vortices are likely generated in places with extremely strong fields, such as magnetars or magnetized accretion disks around black holes [3]. The present result suggests a possibility that magnetic fields in neutron stars and black holes play an important role in the interpretation of many observed phenomena. In particular, the photon vortices may be dominant in high energy region although there is no coherent structure at the macro level.

In this work, furthermore, we calculate the ratios of the photon absorption transition probabilities of photon vortices with Bessel wave to photons described by the plane wave [4]. The result shows enhancement of excitation of states with large total angular momentum by optimization of the divergence angle of the incident photon vortex in momentum space. However, the average cross section for the photon vortex turns out to be identical with that for the plane wave. Therefore, even when Bessel photons are predominantly produced in astrophysical environments, the isotopic abundances of the synthesized elements are not changed.

[1] L. Allen, et al. Phys. Rev. A 45, 8185 (1992).
[2] Z.-W, Lu, et al., Phys. Rev. Lett. 131, 202502 (2023).
[3] T. Maruyama, et al. Phys. Lett. B826. 136779 (2022).
[4] T. Maruyama, et al. Astro. J. 975, 51 (2024).

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