Measured Polarization Components of Nonlinear Thomson Scattering

J. Peatross, N. Atkinson, D. Hodge, B. Pratt, M. Romero, C. Schulzke, and M. Ware
Department of Physics and Astronomy, Brigham Young University, Provo, UT 84602, USA
peat@byu.edu

Abstract: We measure fundamental, second, and third harmonics of nonlinear Thomson scattering emitted by free electrons out the side of a laser focus with 10^{18} W/cm^2. The redshifted photons show distinct spatial patterns when resolved by polarization. © 2020 The Authors

1. Calculations

In their landmark publication a half century ago, Sarachick and Schappert developed the classical theory of nonlinear Thomson scattering in an intense laser field [1]. At relativistic intensities, electrons scatter both odd and even harmonics into a far-field spatial pattern. Electrons drift forward as they oscillate in the laser field, owing to both the electric and magnetic components of the Lorentz force. In their average rest frame, electrons execute a figure-8 motion, which gives rise to emission patterns such as those shown in Fig. 1, which are calculated for individual polarization components.

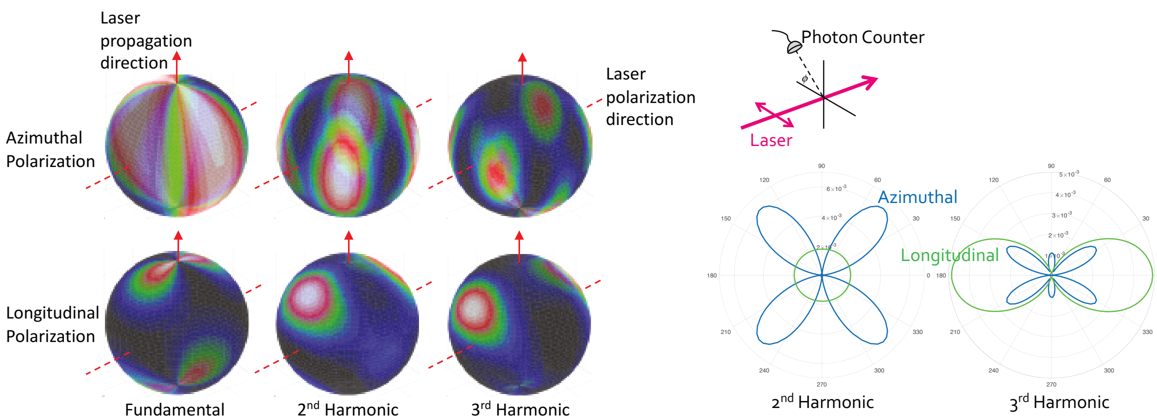

Fig. 1. Calculated 'latitude' (upper left) and 'longitude' (lower left) polarization components of fundamental, second harmonic, and third harmonic nonlinear Thomson scattering in the far field. Electrons are stimulated by linearly-polarized 800 nm light at 1.5×10^{18} W/cm^2. The intensities of harmonic polarization components are shown again (right) in the plane perpendicular to laser propagation.

2. Measurements

Nonlinear Thomson scattering was first observed by Chen *et al.* in the late 1990s [2]. They measured the spatial distribution of second and third harmonic light scattered out the side of their laser focus at various angles.

We have made the first *polarization-resolved* measurements of fundamental, second-harmonic, and third-harmonic nonlinear Thomson scattering. To minimize possible plasma effects, electrons are donated from low-density helium (~10^{-3} – 1 Torr) in a Ti:sapphire laser focus that nominally reaches intensities above 10^{18} W/cm^2. Fig. 2 shows the number of in-band photons registered during 1000 laser shots as a function of angle in a plane perpendicular to the laser propagation – out the side of the focus. Measurements of the scattered radiation are made via photon counting, with the laser firing at 10Hz. Our unique experimental approach combines techniques of quantum optics with high-intensity laser interactions. Photons arriving promptly within a 2 ns window are counted while a relatively large number of 'noise' photons arriving later are ignored. The backfilled pressure of the helium is adjusted so that about 10% of the laser shots register a photon in the prompt time window. The fundamental and second harmonic photons are measured using an avalanche photodiode. The third harmonic is measured using a photomultiplier tube operating in Geiger mode. A 100 μm-long section of the laser beam, centered on the focus from the side, is imaged with f/2 optics onto the end of a glass fiber leading to the detector. A polarizer is placed in front of the collection lens.

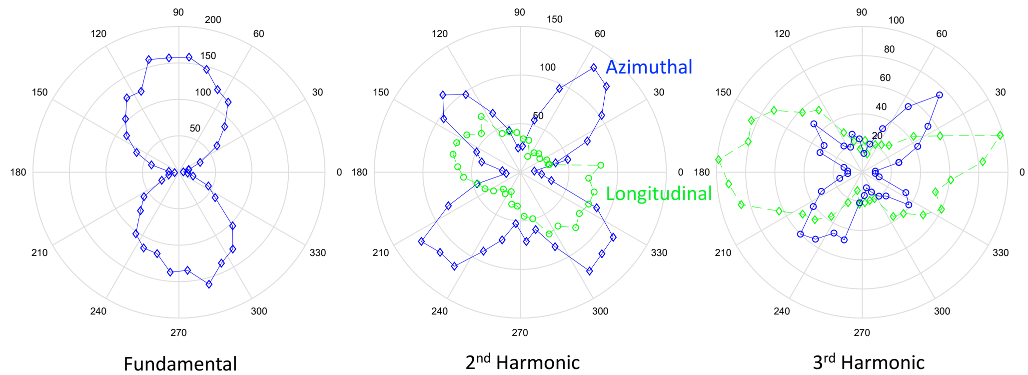

Fig. 2. Nonlinear Thomson scattering measurements as a function of angle in the plane perpendicular to the laser focus. Free electrons are stimulated by linearly-polarized 800 nm, 40 fs laser pulses with estimated peak intensity above 1.5×10^{18} W/cm^2 when tightly focused with $w_0 \sim 4$ µm. Photon counts are registered for both azimuthal and longitudinal polarization components in the following redshifted bands: 900 nm ± 20 nm (fundamental), 450 nm ± 20 nm (2nd harmonic), and 310 nm ± 5 nm (3rd harmonic).

3. Discussion

As described above, Fig. 2 plots measured polarization-resolved nonlinear Thomson scattering. The different polarization components in the scattered light are associated with different aspects of the figure-8 motion executed by the relativistic free electrons. In turn, this motion is driven by the electric and magnetic field components of the laser. These measurements therefore have the potential to reveal characteristics of the laser vector field distribution in the focus. Presumably, the distortions in the measured patterns of Fig. 2, when compared to the simulations of Fig. 1, indicate artifacts in our tight laser focus. Indeed, there is recent interest in using Thomson scattering to diagnose and characterize the focused pulses of ultra-intense laser systems [3].

This work is supported by the National Science Foundation under grant No. 1708185.

References

[1] E. S. Sarachik and G. T. Schappert, "Classical Theory of the Scattering of Intense Laser Radiation by Free Electrons," Phys. Rev. D **1**, 2738 - 2753 (1970).

[2] S. Y. Chen, A. Maksimchuk, and D. Umstadter, "Experimental observation of relativistic nonlinear Thomson Scattering," **396**, 653 - 655 (1998).

[3] C. Z. He, A. Longman, J. A. Pérez-Hernández, M. de Marco, C. Salgado, G. Zeraouli, G. Gatti, L. Roso, R.Fedosejevs, and W. T. Hill III, "Towards an in situ, full-power gauge of the focal-volume intensity of petawatt-class lasers," Opt. Express **27**, 30020-30030 (2019).