Polarization-Resolved Single-Photon Measurements of Nonlinear Thomson Scattering

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Abstract: We report measurements of polarization-resolved nonlinear Thomson scattering made using single-photon detection techniques in a regime of low density electrons. This low density allows the study of electron dynamics in a high-intensity focus.

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1. Experiment

Relativistic nonlinear Thomson scattering occurs when strongly driven electrons emit harmonic light out the side of an intense laser focus. This effect was first observed by Chen, Maksimchuk and Umstadter [1] in a plasma near atmospheric density. In a driven plasma, other effects can compete with the nonlinear Thomson scattering signal, including continuum generation from self phase modulation, electron-electron bremsstrahlung, electron-ion bremsstrahlung, and harmonics due to a transverse electron-density gradient. Nevertheless, Chen et al. were able to confirm that the desired nonlinear Thomson scattering primarily contributed to the measured signal.

In our experiment, we study for the first time the added dimension of polarization in nonlinear Thomson scattering emission. To accomplish this, we evacuate a chamber and then backfill with helium to a pressure near 10^{-4} Torr. We focus a short pulse Ti:sapphire laser into the rarified helium to achieve a peak intensity near 1×10^{18} W/cm^2. The laser first liberates electrons from the helium and then drives them at relativistic speeds, generating the nonlinear Thomson scattering. The scattered light is collected into a fiber using one-to-one imaging, spectrally filtered using bandpass filters, and then detected using single-photon avalanche photodiodes (see Fig. 1). In addition to lateral motion, the laser fields cause the electrons to move in the direction of the laser at a high fraction of the speed of light. Thus, the emitted fundamental photons are red-shifted to near 900 nm, while the emitted 2nd and 3rd harmonics are shifted to near 450 nm and 300 nm, respectively. The laser is linearly polarized and the polarization direction is controlled with a waveplate (not shown on the diagram), while the polarization of the emitted photons is analyzed using a polarizer placed at the entrance of the collection system. The low density and single-photon detection allow us to avoid many of the potential noise sources enumerated above.

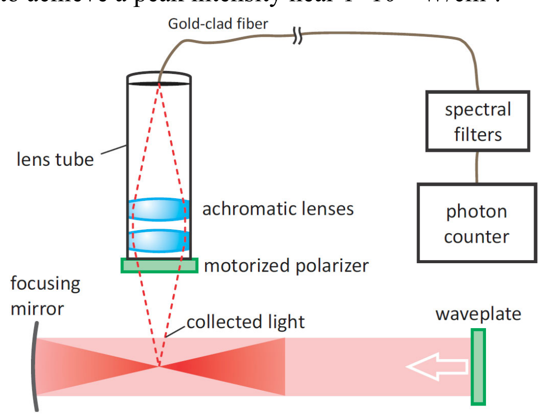

Figure 1 Schematic of the setup used for the measurements

2. Predictions

We numerically modeled and plotted the expected polarization-resolved angular distribution of the fundamental and the second and third harmonic emission perpendicular to the laser beam, as seen in Fig. 2. By rotating the laser polarization, one can effectively trace out this pattern as a function of the azimuthal angle φ, measured relative to the laser's polarization direction as schematically depicted in Fig. 2(a). Plot 2(b) shows the spatial distribution of total emission for first harmonic (fundamental), 2nd harmonic, and 3rd harmonic (N = 1,2,3 respectively), which has been previously described and observed. However, by placing a linear polarizer in front of our detector to analyze the polarization of the emitted light we are able to resolve more structure in the scattered light. Our calculated polarization-resolved 2nd and 3rd harmonic scattered light is shown in plots 2(c) and 2(d). Some rich and interesting polarization behavior is apparent.

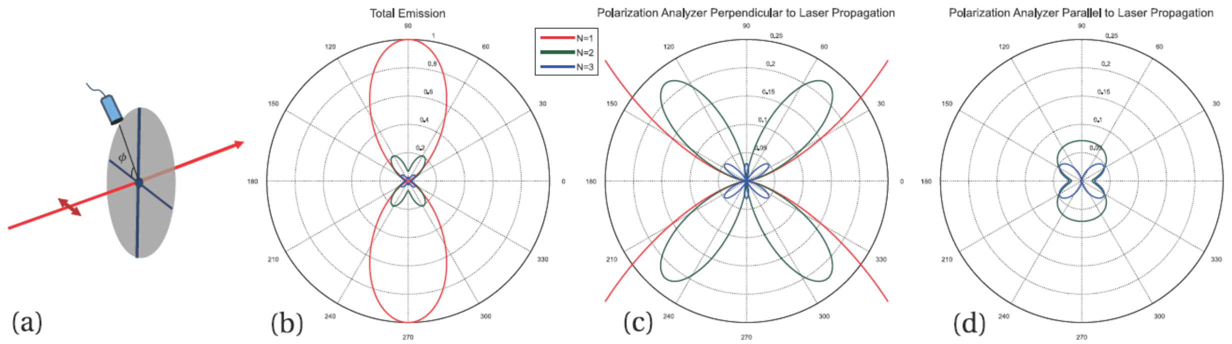

Figure 2 (a) Schematic of nonlinear Thomson-scattering measurements in a plane perpendicular to laser propagation for 800 nm light at 1.5×10^{18} W/cm^2. (b) Total light emission as a function of detector angle φ: fundamental $N = 1$, 2nd $N = 2$, and 3rd harmonic $N = 3$. (c), (d) Polarization-resolved emission.

3. Measurements

A sample of the experimental measurements of nonlinear Thomson scattering for the 2nd harmonic using our apparatus are shown in Fig. 3. The blue diamonds and red stars represent measured data, while the solid lines indicate the corresponding simulated emissions. These measurements correspond to the analysis polarizer settings shown in the green $N = 2$ curves plotted in Figs. 2(c) and 2(d). The measured data show good qualitative similarities to the calculations. Some of the differences between simulation and measurement can be meaningfully associated with imperfections in the laser focus for diagnostic purposes.

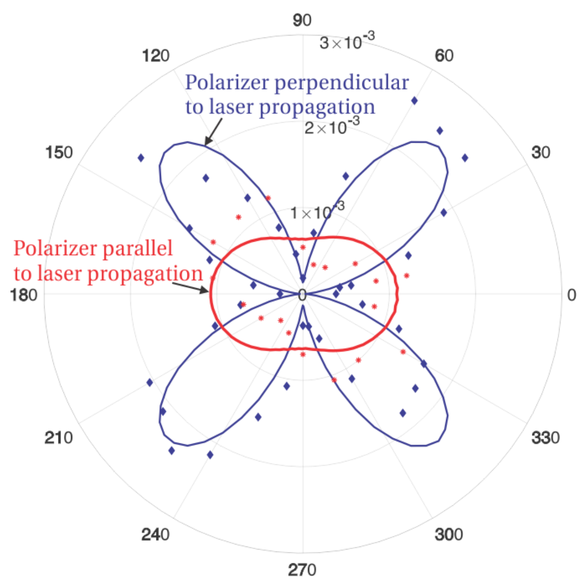

Figure 3 Experimental measurement of nonlinear Thomson scattering for the second harmonic with analysis polarizers oriented as in (a) Figure 2(c) and (b) Figure 2(d)

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4. References

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