Production of High Harmonic X-ray Radiation from Non-linear Thomson Scattering at LLNL PLEIADES

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Abstract:
We describe an experiment for production of high harmonic x-ray radiation from Thomson scattering of an ultra-short high power density laser by a relativistic electron beam at the PLEIADES facility at LLNL. In this scenario, electrons execute a “figure-8” motion under the influence of the high intensity laser field, where the constant characterizing the field strength is expected to exceed unity: \( a_{\text{eff}} \approx \frac{eE}{m_0c^2} \gamma \). With large \( a_{\text{eff}} \), this motion produces high harmonic x-ray radiation and significant broadening of the spectral peaks. This paper is intended to give a layout of the PLEIADES experiment, along with progress towards experimental goals.

Background:
• High brightness, ultra-fast x-ray source based on a head-on and side-on scattering geometry have been demonstrated (e.g. Proceson Laser Electron Inter Action for the Dynamical Evaluation of Structures – PLEIADES).
• Backscattered x-ray exhibits linear spectral distribution characteristic, i.e., a single spectral line centered at \( \nu_0 \), with a broad spectral line width from the electron beam energy spread and the emittance effects.
• Non-linear Thomson scattering observed:
  \[ a_{\text{eff}} \approx \frac{0.85 \times 10^{12}}{2.5 \times 10^6} \gamma, \]
  \[ \frac{1}{\sqrt{V}} \approx \frac{a_{\text{eff}}}{V} \approx \frac{0.2 \times 10^{10}}{10^{15} \text{W/cm}^2} \]
• Non-linear effects manifest by Doppler down-shift in x-ray frequency and generation of harmonics at integer multiples. Odd harmonics appearing on-axis and even harmonics appearing off-axis.

Linear Thomson scattering
\[ a_{L} < 0.01 \]

Non-linear Thomson scattering

Analog: Strong Wiggler Field X-Ray Harmonic production

Electron parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron beam energy</td>
<td>50 MeV</td>
</tr>
<tr>
<td>Electron rate (9 µm)</td>
<td>9 µm laser peak</td>
</tr>
<tr>
<td>Normalized emittance (5 mm-rad)</td>
<td>9 µm laser peak</td>
</tr>
<tr>
<td>Energy spread</td>
<td>2%</td>
</tr>
<tr>
<td>Total electron charge</td>
<td>300 pC</td>
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</table>

Electron beam parameters

Laser parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Laser wavelength</td>
<td>820 nm</td>
</tr>
<tr>
<td>Laser peak power</td>
<td>10 TW</td>
</tr>
<tr>
<td>Laser pulse width</td>
<td>9 µm</td>
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<tr>
<td>Laser periods</td>
<td>20</td>
</tr>
<tr>
<td>Rayleigh length</td>
<td>1.24 mm</td>
</tr>
</tbody>
</table>

Non-linear Thomson Spectral Simulations:
• The “far-field” spectral distributions obtained from the Hartmann-Jacobi equation with boundary conditions \( n_0 = \text{max}(g_0 + d x, g_0 + d y) \) and \( d y = e E c / m_0 c^2 \approx \gamma c / V \) (G. A. Krafft, Phys. Rev. Lett. 92, 20, 2004).
• The scattered intensity obtained:
  \[ I(\nu) \propto \left| \frac{dE_{\text{in}}}{d\Omega} \right|^2 \left| \frac{dE_{\text{out}}}{d\Omega} \right|^2 \approx \frac{1}{\nu_0^2} \frac{d\Omega}{d\Omega} \epsilon \phi \Omega \right| n_0 \right|^2 \]
• The scattered intensity is thus proportional to the scattering angle and electron beam emittance.
• The scattered intensity and correlation is expected to be an order of magnitude higher than the far-field contributions.

The two permanent magnet dipole (PMD) located inside a teflon (Teflon) tube is used to deflect the electron beams into the beam line located outside at 30 degrees from the x-ray beam axis. The beam is transported to the Thomson facility.

Non-linear Thomson x-ray facility:

• A Thomson scattering produced 96 MeV, 30 fs pulse with a linearly polarized 81.557 MHz, 0.6 fs pulse. The signal is observed in the far-field outside of the Thomson facility. The second harmonic is observed in the far-field.

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The Thomson x-ray facility:

• The experimental chamber has been designed to contain both laser and electron optical systems, a precise aligned laser and electron beam alignment system, and a beam monitoring and diagnostic system, which is used for momentum spread measurements of Thomson x-rays. The experimental chamber is equipped with a 30 fs laser pulse, which is used for Thomson x-ray production.

• The electron beam is transported to the Thomson x-ray facility at a linear energy of 250 MeV, with a spread of 10%.

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