Thomson scattering measurements in the collective and non-collective regime in laser produced plasmas

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We present simultaneous Thomson-scattering measurements of light scattered from ion-acoustic and electron plasma fluctuations in a N_2 gas jet plasma. By varying the plasma density and temperature we observe the transition from the collective regime to the non-collective regime for the electron feature. In the collective regime high electron plasma wave phase velocities lead to mildly-relativistic scattering and first order v/c corrections in the Thomson-scattering form factor must be taken into account. We propose future experiments in the fully-relativistic regime at the Omega Laser Facility to study the relativistic effects on electron screening.

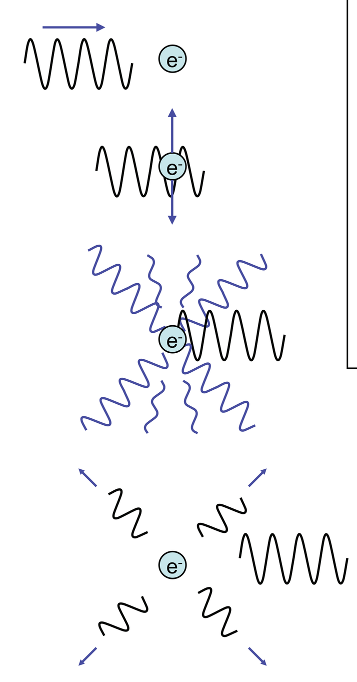
Thomson Scattering

- Electromagnetic wave interacts with charged particle
  - Electric field causes particle to accelerate
- Accelerating charge radiates in each direction
  - Radiated power depends on direction

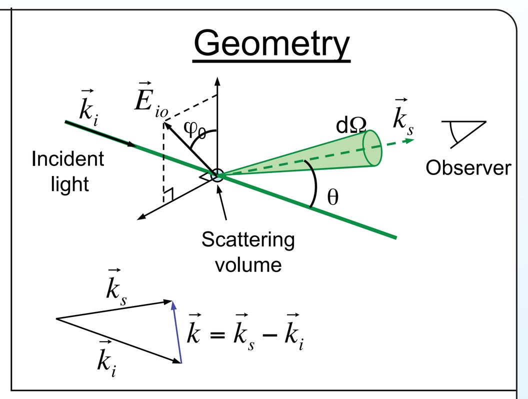
$$P_r(\vec{R}) = \frac{q^4 E_{io}^2}{8\pi m^2 c^3}\left(1-\sin^2\theta\cos^2\varphi_0\right)$$

(For polarized radiation)

- Scattered light is Doppler-shifted based on motion of the charge



Geometry



Plasma Effects

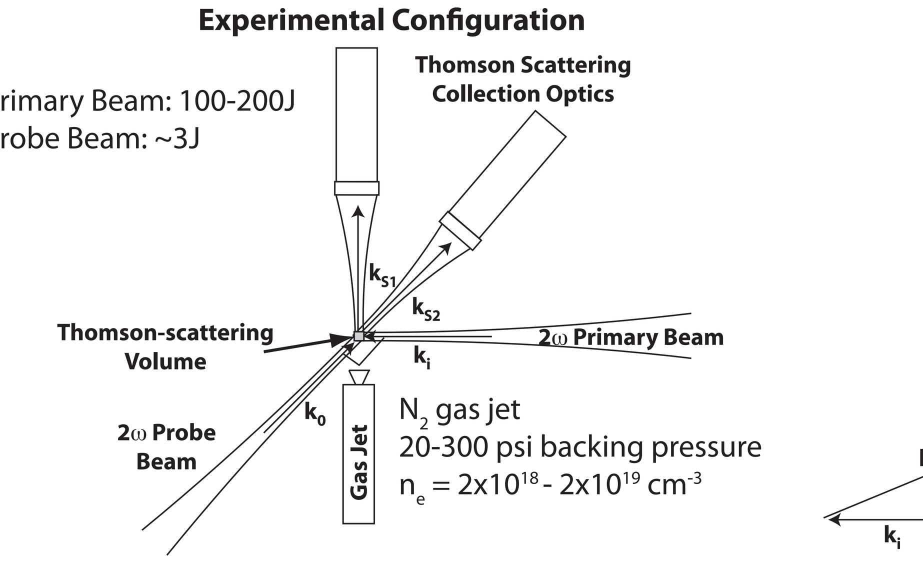
$\alpha = 1/k\lambda_{De}$

- Correlated charge positions yield collective scattering for $\alpha > 1$

Thomson scattering from nitrogen has been observed at the Jupiter Laser Facility

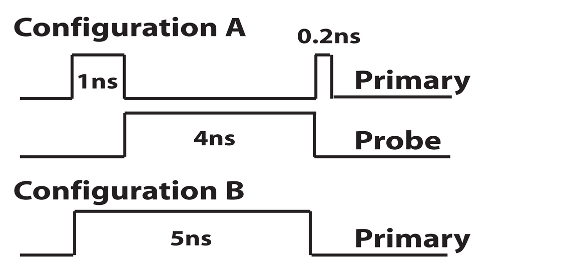
Experimental Configuration

Primary Beam: 100-200J
Probe Beam: ~3J

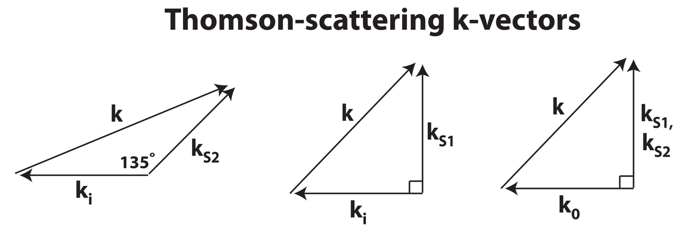


N_2 gas jet
20-300 psi backing pressure
$n_e = 2\times10^{18} - 2\times10^{19}$ cm^{-3}

Laser Configuration

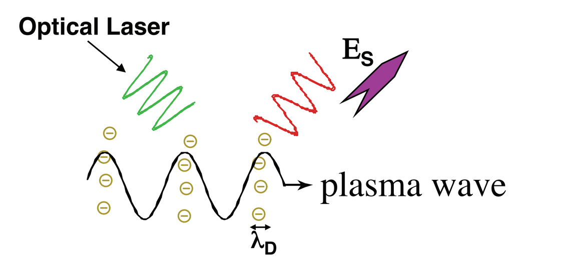


Thomson-scattering k-vectors

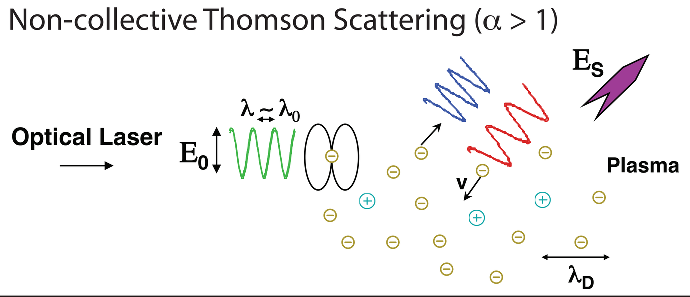


The scattering parameter (α) was scaled from 0.8 to 2.0 by changing the density and temperature.

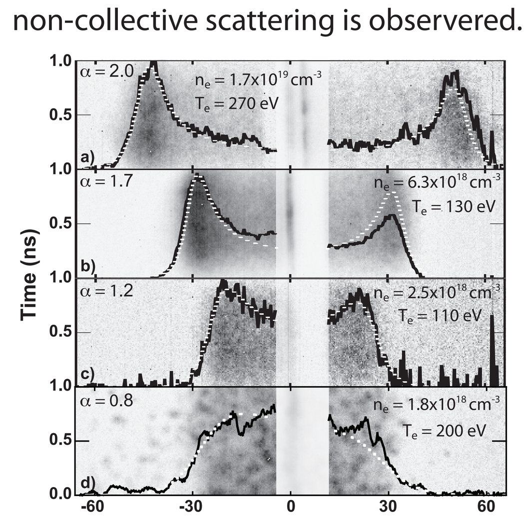
Collective Thomson Scattering ($\alpha > 1$)



Non-collective Thomson Scattering ($\alpha > 1$)



A transition from collective scattering to non-collective scattering is observed.



Due to the high phase velocity of the probed electron-plasma waves relativistic effect must be taken into account.

The power scattered by Thomson scattering,

$$\frac{P_s}{P_i} = \sigma_e n_e S(k,\omega) G(k,\omega) dz d\Omega$$

Geometrical factor assuming no polarization dependence,

$$G(k,\omega) = 1 + \frac{2\omega}{\omega_i}$$

First order relativistic correction (We are currently exploring fully relativistic geometric factors)

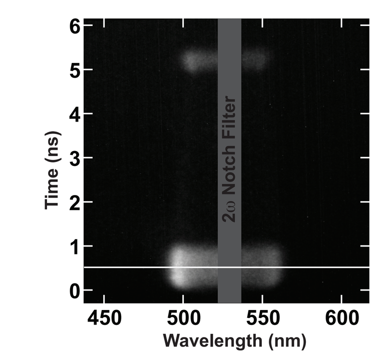
The spectral density function,

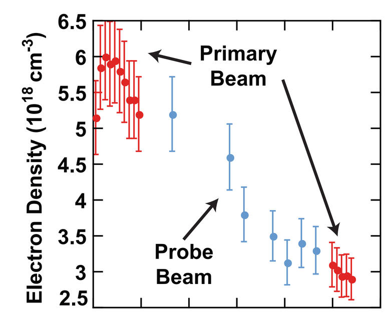
$$S(k,\omega) = \frac{2\pi}{k}\left|1-\frac{\chi_e}{\varepsilon}\right|^2 f_{e0}\left(\frac{\omega}{k}\right) + \frac{2\pi}{k}\left|\frac{\chi_e}{\varepsilon}\right|^2 f_{i0}\left(\frac{\omega}{k}\right)$$

Classically χ_e, ε, f_{io} and f_{eo} are all calculated assuming maxwellian distributions, for high phase velocities this assumption leads to significant error in the calculated spectrum.

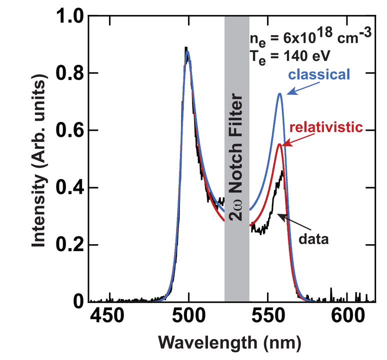
T_e and n_e have been measured from the electron feature

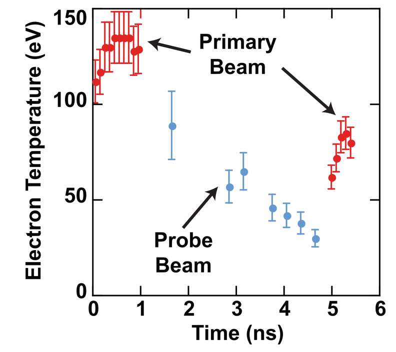
A 2w notch filter is used to block scattering from the ion feature that is much more intense.





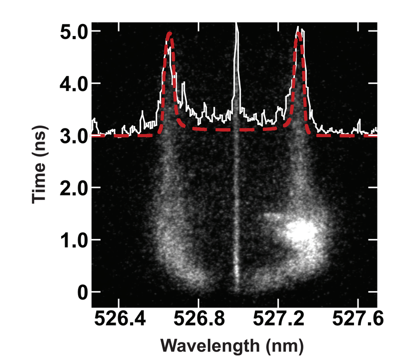
Due to the high phase velocity of the electron plasma wave relativistic effects have a significant impact on the scattered-spectrum





Once the electron temperature and density have been measured the average charge state can be measure with the ion feature.

Thomson scattering from ion-acoustic waves

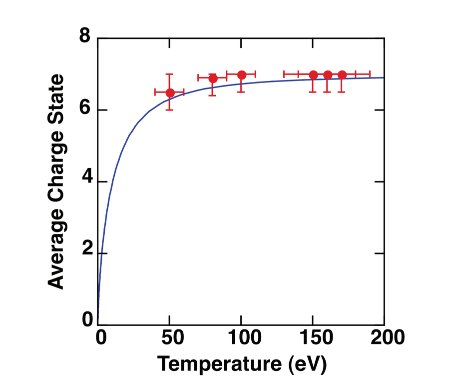


Laser Configuration B

In the fluid limit the separation between Thomson-scattering ion-acoustic peaks is,

$$\Delta\lambda = \frac{4\lambda_0}{c}\sin\left(\frac{\theta}{2}\right)\sqrt{\left(\frac{T_e}{M_i}\right)\cdot\left(\frac{Z}{\left(1+k^2\lambda_{De}^2\right)}+\frac{3T_i}{T_e}\right)}$$

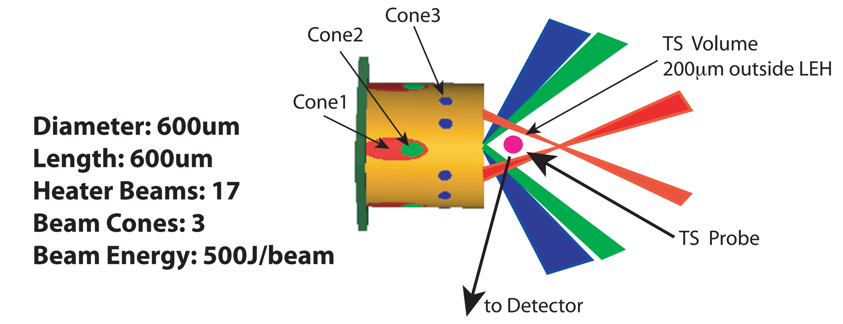
Average charge state vs. Temperature



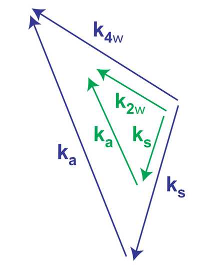
The measured average charge state is comparedto the Thomas-Fermi ionization model.

Future experiments are proposed using the characterized high-temperature half-hohlraum target platform.

Diameter: 600um
Length: 600um
Heater Beams: 17
Beam Cones: 3
Beam Energy: 500J/beam

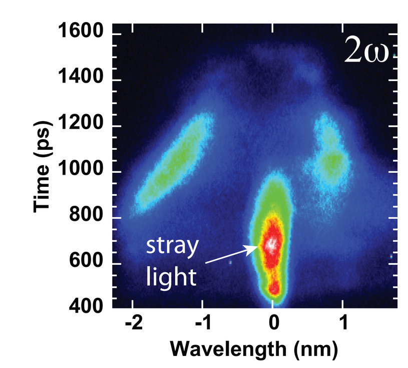


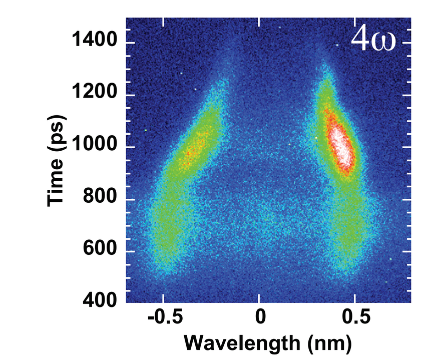
Thomson-scattering geometry



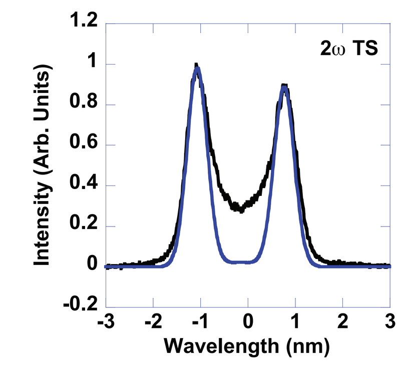
Thomson-scattered light is imaged onto the entrance slit of a 1-meter spectrometer which is coupled to a streak camera.

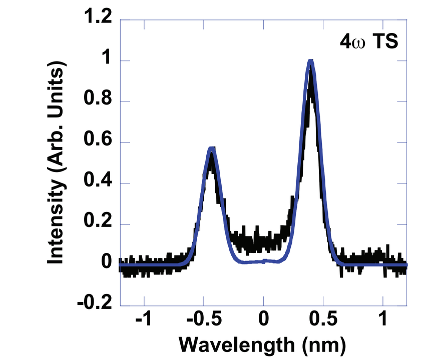
Multi-color Thomson scattering was used to measure the electron temperature and density outside the laser entrance hole.





Thomson-scattered light is measured for two probe wavelengths, 263nm (4ω) and 527 nm (2ω).





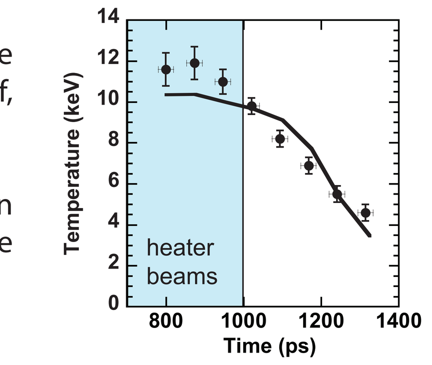
The experimental data (black lines) is compared to the calculated spectrum (blue lines) for the following plasma parameters at 1.2 ns:

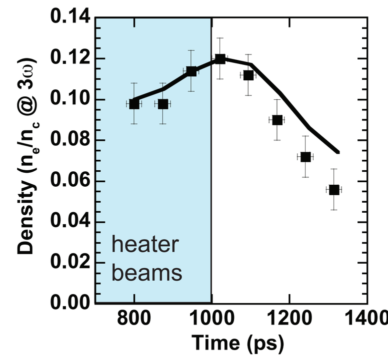
T_e = 6.2 keV
n_e = 8.1x10^{20} cm^{-3}
Z = 63
$T_i = T_e/2$

The electron temperature ranged from 3 keV to 12 keV and the density from 5x10^{20} to 1x10^{21} cm^{-3} over 1 ns.

The electron temperature and density have been measured assuming a charge state of, Z=40Te$^{0.2}$ [1].

The experimental measurements have been compared to Lasnex simulations using the DCA ionization model shown as black lines.

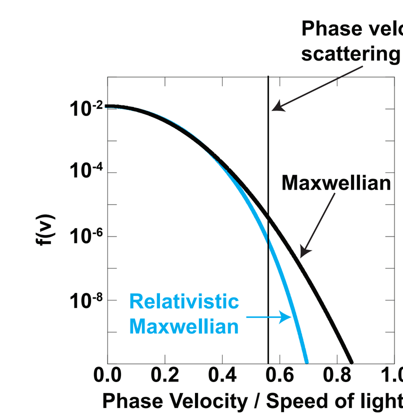




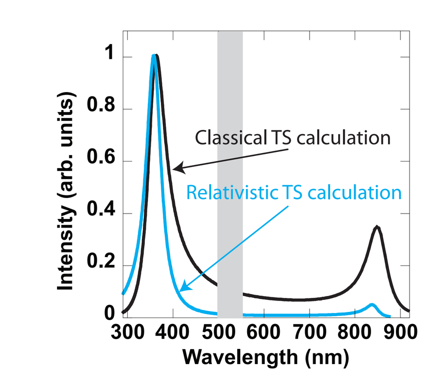
[1] Lindl et al. Phys Plasmas (2004) vol. 11 (2) pp. 339-491

This target platform is ideal for investigating relativistic electron screening effects in a high-temperature plasma.

Comparing the slope of the Maxwellian distribution and the relativistic Maxwellian shows for what phase velocities relativistic effects are important.



Relativistic effects should be detectable in the asymmetry of the Thomson-scattered peaks.



For the high-temperature hohlraum plasma conditions large relativistic effects are expected.

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