PREPARED FOR THE U.S. DEPARTMENT OF ENERGY,
UNDER CONTRACT DE-AC02-76CH03073

PPPL-3742
UC-70

PPPL-3742

Comment on "Generation of Electromagnetic Pulses from Plasma Channels Induced by Femtosecond Light Strings"

by

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September 2002

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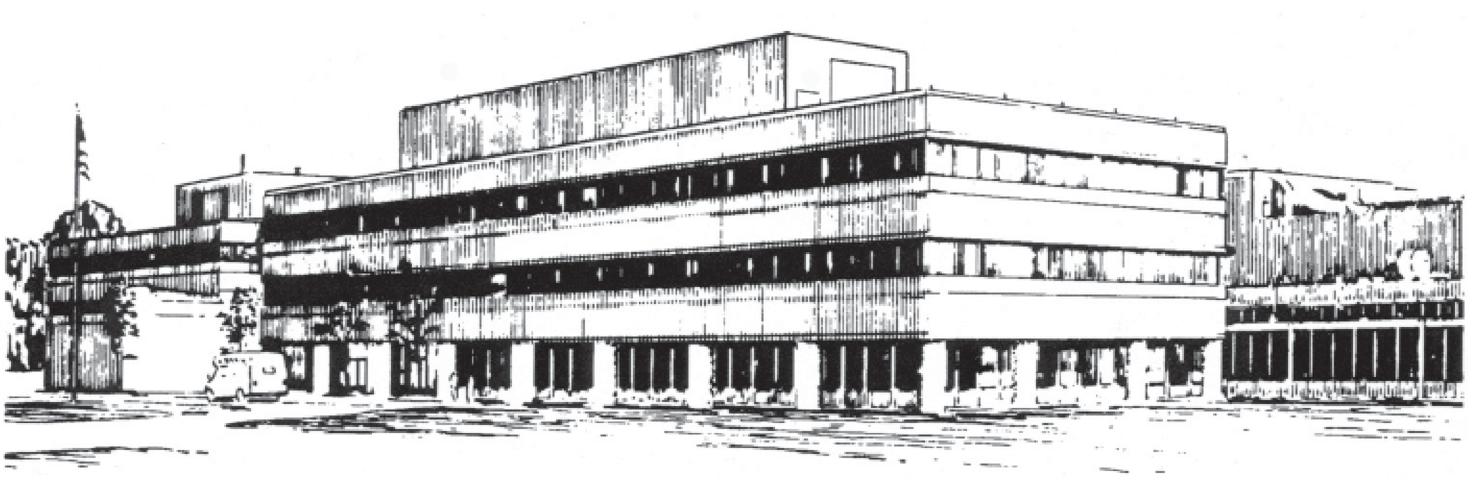

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Comment on "Generation of Electromagnetic Pulses from Plasma Channels Induced by Femtosecond Light Strings"

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In a recent Letter [1], Cheng *et. al.* calculated/predicted several new effects: that (a) fraction of the short laser pulse momentum can be imparted to plasma electrons via collisional damping of the laser, thereby exciting a long-lived (longer than an oscillation period) plasma wave, which (b) gives rise to a spatially uniform dipole moment of a plasma, which (c) emits far-field narrow-band radiation at the plasma frequency ω_p over the recombination time of the plasma. We claim that the calculation of the effect (a) is in error and the predicted effects (b,c) do not occur as described. In fact, predicted narrow-band emission at ω_p would not occur even if the momentum transfer and the dipole excitation were calculated correctly.

(a) Cheng *et. al.* calculated that an electron absorbing laser radiation due to collisions at a rate γ is displaced by a distance ξ_0, given by Eq. (8), which does not depend on γ because it is proportional to the product of the gained momentum ($\propto \gamma$, according to Eq. (7)) and the drift time $T \approx \gamma^{-1}$. This argument holds only if there is no restoring force $-\omega_p^2 \xi$ from the plasma ions over this period of time. Because the restoring force can only be neglected for $t \ll \omega_p^{-1}$, the calculation of Cheng *et. al.* is valid only if $\gamma \gg \omega_p$. For such highly collisional plasmas it is not sensible to talk about plasma oscillations since they decay within less than one period (or about a picosecond for the chosen plasma density) due to electron-neutral collisions. This contradicts the authors' claim that the duration of the plasma oscillations is limited by the plasma recombination.

Plasma oscillations can last longer than one period if $\gamma \ll \omega_p$, but the oscillation amplitude is reduced from that given by the authors by a factor γ/ω_p. For example, for $\gamma = 3 \times 10^{11}$ s^{-1} (which corresponds to one undamped plasma oscillation), the correct displacement of the plasma electron by the radiation pressure force $F_{\rm RP}$ is a factor 6 smaller than claimed by Cheng *et. al.* . In other words, under no circumstances can the plasma oscillations with amplitude ξ_0 and lifetime $> \omega_p^{-1}$ be excited via collisional absorption force $F_{\rm RP}$ given by Eq. (7). Moreover, Cheng *et. al.* overlooked the usual ponderomotive force $F_P = -\dfrac{e^2}{2m\omega_L^2}\partial_z |E_L|^2 = \dfrac{e^2}{2m\omega_L^2 v_g}\partial_t |E_L|^2$ because they used an approximate relation between electric and magnetic fields. When collisions are negligible $F_P \gg F_{\rm RP}$ and $\xi_0^{\rm P} = (e^2/2m^2 c\omega_L^2)\displaystyle\int_{-\infty}^{+\infty} dt |E_L|^2$ [2]. The authors' claim that the usual ponderomotive force (which is proportional to the spatial intensity gradient) is too small for light strings of 100μm diameter and centimeter length is wrong: the spatial gradient that matters in this case is inversely proportional to the short pulse length $ct_p \approx 3\mu$m.

(b) Cheng *et. al.* incorrectly assumed that all plasma electrons oscillate in phase regardless of their position z, so that $\dot{\xi}(t,z) \equiv \dot{\xi}(t)$ is a function of time only, producing a uniform current J_z. This can only happen if the plasma oscillations are excited instantaneously by the laser pulse propagating with an infinite speed. In fact, plasma oscillations are set up by the laser pulse at different times $t = z/v_g$, where $v_g < c$ is the group velocity of the pulse. Therefore, $\dot{\xi}(t,z) \equiv \dot{\xi}(t - z/v_g)$, and the longitudinal wavenumber of the current perturbation with frequency $\omega_{\rm osc}$ is $k_z = \omega_{\rm osc}/v_g$. For $L = 1$ cm long plasma filament this translates into the phase difference of $\Delta\phi = \omega_p L/c \approx 60$ for plasma oscillations excited along the light string. The destructive interference of these oscillations will surely destroy the radiation conjectured by Cheng et. al.

(c) The idea of using a laser-driven plasma filament for radiation generation using the setup of Ref. [1] is erroneous for two reasons. First, it is impossible to produce far-field radiation by creating an excitation which moves uniformly with a subluminal speed $v_g < c$. Indeed, for electromagnetic radiation in free space $k_\perp^2 = \omega_{\rm osc}^2/c^2 - k_z^2 < 0$, and radiation does not propagate out of the plasma channel.

Second, even if the long-wavelength ($k_z \approx 0$) displacement ξ_0 of a plasma column envisioned by Cheng *et. al.* could be set up somehow, it still would not emit narrow-bandwidth radiation at $\omega = \omega_p$. *Plasma waves can never emit radiation at* $\omega_{\rm osc} = \omega_p$ because the displacement current $(1/4\pi)\partial_t \vec{E}_p$ (where $\vec{E}_p$ is electric field of a plasma wave) exactly compensates the plasma current $-en\vec{v}$ prohibiting radiation. While Cherenkov-like radiation is possible when the velocity of the laser pulse exceeds that of the emitted radiation, and was even experimentally observed in electrooptic materials [3], it is not narrow-bandwidth.

Moreover, 2-D oscillations of a narrow plasma column differ substantially [4, 5] from the simplified 1-D case considered by the authors. Cheng *et. al.* erroneously predicted the far-field radiation because Eq. (11) contains a *prescribed* current J_z which is not calculated self-consistently: the effect of $\vec{E}_{\rm rad}$ on the electron motion was neglected. By inserting the prescribed current J_z into Eq. (11) Cheng *et. al.* demonstrated that, not surprisingly, a *driven* electron current emits radiation. This not the same as demonstrating that an initially perturbed plasma filament emits radiation while executing a *self-consistent* plasma oscillation.

This research was supported by the U.S. Department of Energy.

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03/26/01

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