The Antiphysical Review

Founded and Edited by M. Apostol **119** (2005)

ISSN 1453-4436

Laser-Plasma Interaction and Related Processes

M. Apostol
Department of Theoretical Physics, Institute of Atomic Physics,
Magurele-Bucharest MG-6, POBox MG-35, Romania
email: apoma@theory.nipne.ro

Let $\mathbf{A}$ be the potential vector of an electromagnetic field propagating in a plasma with density N. The Maxwell equations give

$$-\Delta\mathbf{A}+\frac{1}{c^2}\partial^2\mathbf{A}/\partial t^2=\frac{4\pi}{c}\mathbf{j} \tag{1}$$

for Coulomb gauge $div\mathbf{A}=0$, where $\mathbf{j}=e\mathbf{v}N$ is the curent density. On the other hand, $m\dot{\mathbf{v}}=e\mathbf{E}=-(e/c)\dot{\mathbf{A}}$, so $\mathbf{j}=-(e^2N/mc)\mathbf{A}$, and (1) becomes

$$-\Delta\mathbf{A}+\frac{1}{c^2}\partial^2\mathbf{A}/\partial t^2=-\frac{4\pi Ne^2}{mc^2}\mathbf{A}\ , \tag{2}$$

whose solutions are polaritons (transverse photons coupled to plasma) of frequency ω given by $\omega^2=\omega_p^2+c^2k^2$. However, this is so for constant density N. For a varying density N, equation (2) must be supplemented by the motion equation of the density N under the action of the electromagnetic field (plasma oscillations included), the two equations becoming non-linear.

In general, solutions of such equations are dispersive, and the plasma refractive index $n=ck/\omega$, where $\mathbf{k}$ is the wavevector, depends on time. This $n=n_0-\dot{n}t$ time dependence in the electromagnetic wave

$$\sim e^{i(kz-\omega t)}=e^{i(\omega n_0 z/c-\dot{n}z\omega t/c-\omega t)} \tag{3}$$

makes the wave front $z=ct/n_0$ experience a frequency $\omega'=\omega[1+(\dot{n}/n)t]$, which exhibits a shift similar to Doppler's. It is also similar to Hawking's and Unruh's frequency shift $\delta\omega/\omega=(a/c)t=t/\tau$, in a reference frame moving with acceleration a, with a characteristic short time τ (leading to a temperature $T=(\hbar/2\pi)(a/c)$, evaporation of black-holes by transforming virtual photons into real ones, and dynamic Casimir force).[1]

In plasmas (whose refractive inedx decreases abruptly) the shift is to the blue, and the electromagnetic wave becomes thereby "chirped" just at the front wave. It may serve as a mechanism of compressing the laser pulse, by cutting down the front wing of the gaussian. A solution of the coupled laser-plasma equations could be looked for by following such instantaneous change in the refractive index just on the front wave.

On the other hand, solutions of non-linear equations have usually a different vacuum when quantized, which may amount to condense the photons to classical lasers field, as in Bogoljubov treatment of superfluidity. The polaritons dispersion relation given above is already suggestive for superfluids spectra. This enhances the occupation number of photon modes, and leads, together with the chirping, to a pulse amplification. It is basically due to plasma currents.

The two non-linear equations discussed above can be conveniently written down by introducing the scalar potential, and using Poisson's equation to relate it to plasma density, as well as the Lorentz force which acts upon density. In this form the equations (called Zakharov equations[2]) are useful for studying the coupling between longitudinal plasma waves and transverse plasma waves,[3] especially for a grating of density (and of the refractive index) produced by quantum beats in two laser beams detuned by plasma frequency. Indeed, the quantum beats of two parallel laser beams introduces an oscillating ponderomotive force (according to spatial variation of the potential energy), which, in turn acts upon the electromagnetic field as a spatial lattice. We expect therefore a mode-locking (as for energy gaps), and, very interesting, a multitude (a cascade) of radiation sidebands, much more narrow in frequency, and separated in time by the beating period. A mechanism of compression based on these cascade sidebands occurring in plasma propagating two plasma-beating laser beams has been proposed recently.[4]

References

[1] E. Yablonovitch, Phys. Rev. Lett. **62** 1742 (1989)

[2] P. A. Robinson, Revs. Mod. Phys. **69** 507 (1997)

[3] B. I. Cohen et al, Phys. Rev. Lett. **29** 581 (1972)

[4] S. Kalmykov and G. Shvets, Phys. Rev. Lett. **94** 235001 (2005)