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Comment on "Direct Observation of Optical Precursors in a Region of Anomalous Dispersion"

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In a recent Letter [1], Jeong, Dawes and Gauthier (JDG) claim to have achieved the first direct measurement of "optical precursors" for a step-modulated field propagating through an anomalously dispersive medium. In fact such transients have been evidenced previously [2]. They are not identifiable with precursors (unless one considers that any coherent transient propagating in a dilute medium at the velocity c is a precursor) and they can be interpreted in very simple physical terms. We use the notations of [1] in our discussion.

The Sommerfeld-Brillouin precursors are strongly non-monochromatic signals preceding the arrival of the quasi-monochromatic wave at the frequency ω_c of the optical carrier. They occur in a *bulk* medium with a *broad* absorption line and a *large* optical thickness when the incident field is switched on instantaneously or, at worst, in a time T_r comparable to the optical period $T_0 = 2\pi/\omega_0$ [3]. None of these conditions is met in the JDG experiments. The observed transients have a spectrum of very small width [$\Delta\omega/\omega_c = O(10^{-8})$] and thus pertain to the quasi-monochromatic wave. We also remark that the general asymptotic theory, specially adapted to the study of the precursors, fails to explain the experimental results (predicted amplitudes up to 10^{10} times too large, inability to reproduce the oscillatory behavior at large optical thickness [1]). Conversely, the slowly varying amplitude approximation (SVAA) is fully operational since the switching time T_r , although much shorter than the medium response-time, is dramatically long compared to $1/\omega_c$. The signals obtained in [1, 2] then have a simple physical interpretation.

The light transmitted by a dilute medium can indeed be seen as resulting from the interference of the input wave, as it would propagate in vacuum, with the secondary wave emitted by the electric polarization induced in the medium. When the incident field is turned on, the latter does not appear instantaneously and the front of the step-modulated pulse propagates at the velocity c without attenuation. The envelope $e(L, \tau)$ of the transmitted field at later times is obtained by solving the Bloch-Maxwell equation. When the medium is optically thin, it reads $e(L, \tau) \approx E_0\Theta(\tau) - iL\omega_0 p(\tau)/(2\epsilon_0 c)$ where $p(t)$ is the envelope of the polarization induced in $z = 0$. The incident wave (the medium) being resonant (linear), $p(t)$ monotonously increases. For a homogeneously broadened line, we then get $e(L, \tau) \approx E_0\Theta(\tau) [1 - (1 - e^{-\delta\tau})\alpha_0 L/2]$, which provides a satisfactory approximation of the exact result when $\alpha_0 L < 1/2$. The corresponding intensity profile fits fairly well the transient observed by JDG for $\alpha_0 L = 0.41$ (see their Fig.1). Expressions valid at higher orders in $\alpha_0 L$ can be obtained by an iterative procedure but it is more convenient to use the

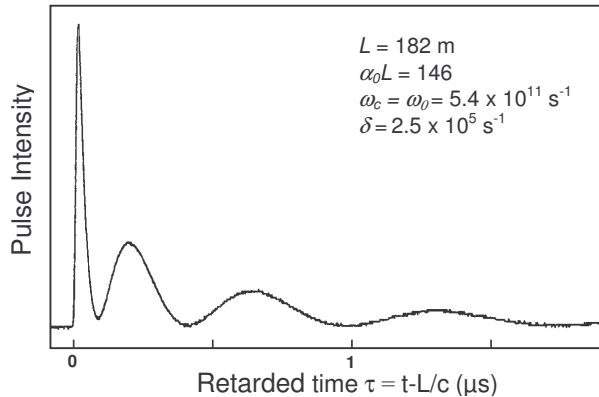


FIG. 1: Response of a optically thick medium to a resonant step-modulated wave. See [2] for details.

exact results obtained by Crisp [4]. From his Eq. (33) giving the medium impulse response, we easily derive

$$e(L, \tau) = E_0 \Theta(\tau) \left[1 - \alpha_0 L \int_0^{\delta \tau} \frac{J_1(\sqrt{2\alpha_0 L u})}{\sqrt{2\alpha_0 L u}} e^{-u} du \right] \quad (1)$$

This form (valid whatever $\alpha_0 L$ and τ are) makes again apparent the primary step-modulated wave and the wave emitted by the medium. The first order result is retrieved by remarking that $J_1(x)/x = 1/2 + O(x^2)$ when $x \ll 1$. At moderate optical thickness, the effect of the function weighting e^{-u} in Eq. 1 is essentially to shorten the transient, as observed by JDG for $\alpha_0 L = 1.03$. When $\alpha_0 L \gg 1$, the transient takes an oscillating form. Figure 1 shows the intensity-profile of the transmitted pulse measured for $\alpha_0 L = 146$ [2]. It fully agrees with the prediction of Eq. 1. In particular the maximums of intensity exactly occur at the retarded times $j_{1,n}^2 / (2\alpha_0 L \delta)$, where $j_{1,n}$ is the n^{th} zero of $J_1(x)$. Let us recall that the oscillatory behavior is not reproduced by the standard theory of precursors [1]. Since on the contrary the transients reported in [1, 2] are in perfect accordance with the theoretical predictions by Crisp [4], we suggest, to avoid any confusion, to name them *Crisp transients* instead of Sommerfeld-Brillouin precursors. We finally remark that the validity of the SVAA does not imply that of calculations involving truncated Taylor series expansions of the wave number. For the step-modulated wave considered here, it is clear in particular that the group velocity is not a relevant parameter.

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- [2] B. Ségard, J. Zemmouri, and B. Macke, Europhys.Lett. **4**, 47 (1987).
- [3] Oughstun and Sherman (Ref. [3] of JDG) have indeed shown that the precursors vanish when $T_r \geq 1/\delta$ with $\delta = 0.07\omega_0$, that is when $T_r \geq 2.3T_0$.
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