Теорема площадей фотонного эха в резонаторе и оптически плотной среде

По материалам доклада С.А. Моисеева и Р.В. Урманчеева

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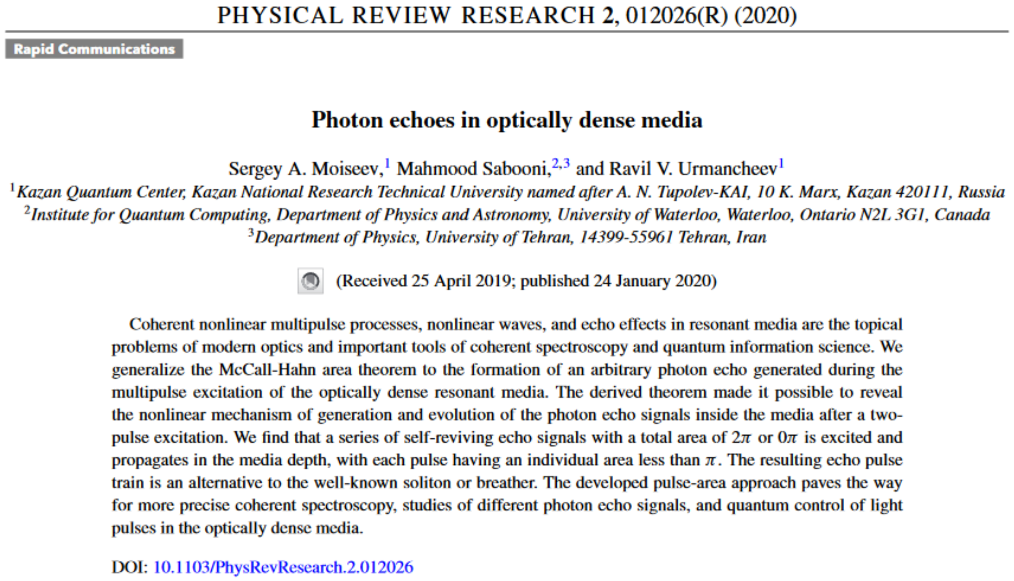

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Rapid Communications

Photon echoes in optically dense media

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Coherent nonlinear multipulse processes, nonlinear waves, and echo effects in resonant media are the topical problems of modern optics and important tools of coherent spectroscopy and quantum information science. We generalize the McCall-Hahn area theorem to the formation of an arbitrary photon echo generated during the multipulse excitation of the optically dense resonant media. The derived theorem made it possible to reveal the nonlinear mechanism of generation and evolution of the photon echo signals inside the media after a two-pulse excitation. We find that a series of self-reviving echo signals with a total area of 2π or 0π is excited and propagates in the media depth, with each pulse having an individual area less than π. The resulting echo pulse train is an alternative to the well-known soliton or breather. The developed pulse-area approach paves the way for more precise coherent spectroscopy, studies of different photon echo signals, and quantum control of light pulses in the optically dense media.

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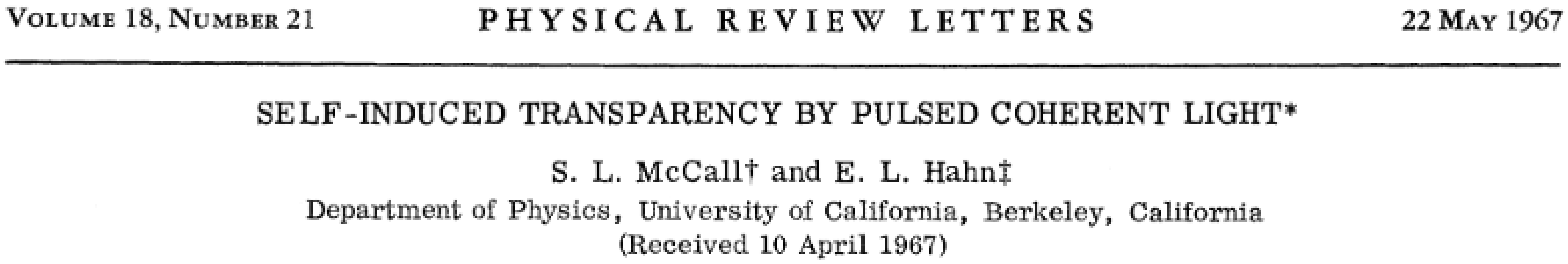

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SELF-INDUCED TRANSPARENCY BY PULSED COHERENT LIGHT*

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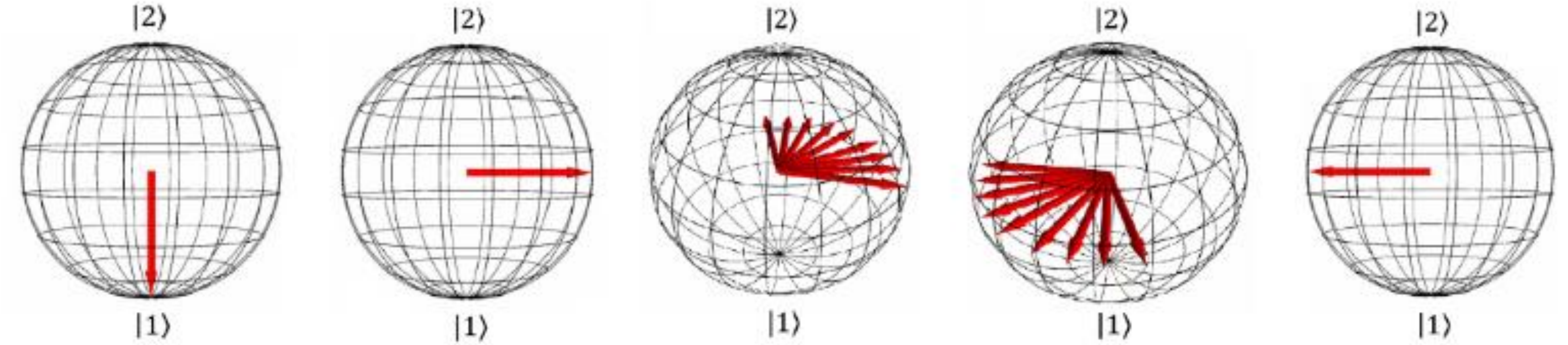
Фотонное эхо

Первый импульс (π/2) создаёт возбужденное когерентное состояние атомного ансамбля

Второй (π) – меняет знак фазы, в результате чего подансамбли снова начинают осциллировать в фазе



Система в основном состоянии

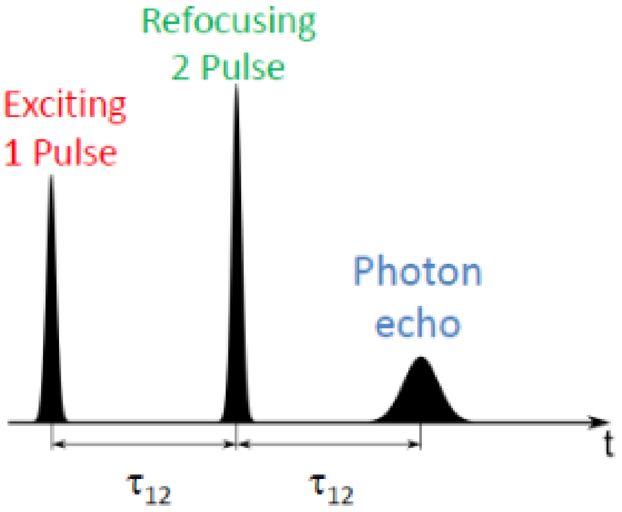
Действие первого импульса

Расфазировка подансамблей

Действие второго импульса

«Синхронизация» подансамблей и излучение сигнала

$$
\begin{aligned}
[\partial_z + c^{-1}\partial_t]\Omega &= i\frac{\mu}{2}\langle P\rangle, \\
\partial_t u &= -\Delta v - \gamma u, \\
\partial_t v &= \Delta u - \gamma v + \Omega w, \\
\partial_t w &= -\Omega v,
\end{aligned}
$$



u, *v*, *w* – компоненты вектора Блоха, P – атомная поляризация $E(t,z) = \varepsilon(t,z)\exp[i(kz-\omega t)] + \text{c.c.}$ - поле, с соответствующей частотой Раби $\Omega(t,z) = (2d/\hbar)\varepsilon(t,z)$

$$\overline{\langle\ldots\rangle} \equiv \int_{-\infty}^{\infty} G(\Delta)\ldots d\Delta$$

Теорема площадей

$\beta = \ln\{\tan[\frac{\theta_1(0)}{2}]\}$ and $\kappa = \tan[\frac{\theta_2(0)}{2}]/\sin[\theta_1(0)]$

Перепишем для площадей импульсов:

$$\theta = \int_{-\infty}^{\infty} dt\,\Omega(t) \qquad \partial_z\theta = \tfrac{1}{2}\alpha w_0(z)\sin\theta(z) \quad \Rightarrow$$

$$\theta_1(z) = 2\arctan\left[e^{-\alpha z/2}\tan\frac{\theta_1(0)}{2}\right],$$

$$\theta_2(z) = 2\arctan\left[\kappa\,\mathrm{sech}\left(\beta - \frac{\alpha}{2}z\right)\right]$$

α - резонансный коэффициент поглощения, $w_0(z)$ - начальная инверсия заселенности (-1 для 1 импульса и $-\cos\theta_1$ для второго)

Суммарная площадь всех эхо-импульсов: $\theta_{\Sigma e}(z) = 2\arctan\left[e^{-\alpha z/2}\tan\frac{\theta_1(0)+\theta_2(0)}{2}\right] - \theta_2(z) - \theta_1(z).$

При $\theta_2(0) < \pi, \theta_1(0)+\theta_2(0) > \pi$ суммарная площадь импульсов эхо стремится к 2π

$\theta_1(0) < \pi/2, \theta_2(0) > \pi$ сумма всех эхо импульсов 0?!

Необходимо исследовать площадь каждого импульса отдельно!

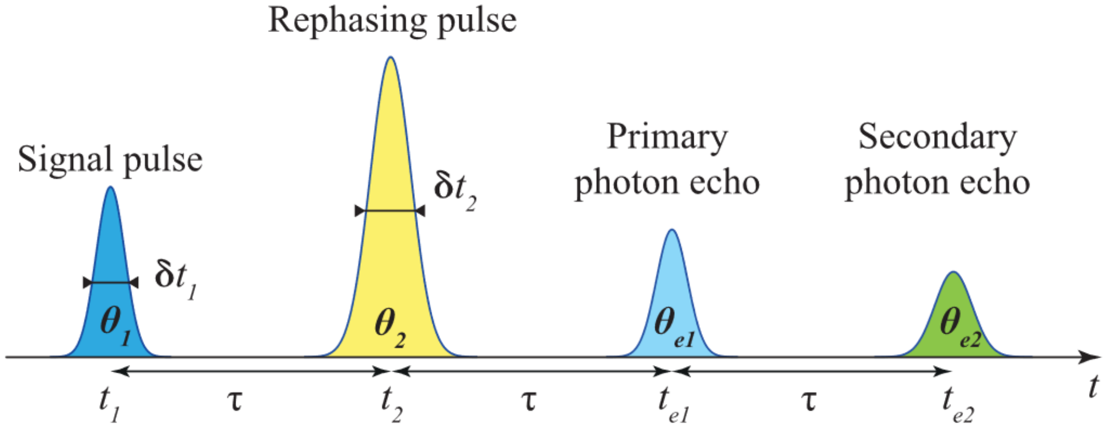


FIG. 1. Time delays and intervals between the pulses involved in the formation of primary and secondary echoes. The pulses are well separated and resonant with atomic transition with large inhomogeneous broadening and long coherence lifetime: $1/\Delta_{\mathrm{inh}} \ll \delta t_{1,2} \ll \tau \ll T_2$.

Теорема площадей

$$v_0(3\tau/2, z) = \Gamma_\tau^2 \sin\theta_1(z) \sin^2 \frac{\theta_2(z)}{2},$$

$$\tilde{w}_0(3\tau/2, z) = -\cos\theta_1(z) \cos\theta_2(z),$$

$$\partial_z \theta(z) = \frac{1}{2}\alpha \left[2v_0(z) \cos^2 \frac{\theta(z)}{2} + w_0(z) \sin\theta(z) \right]$$

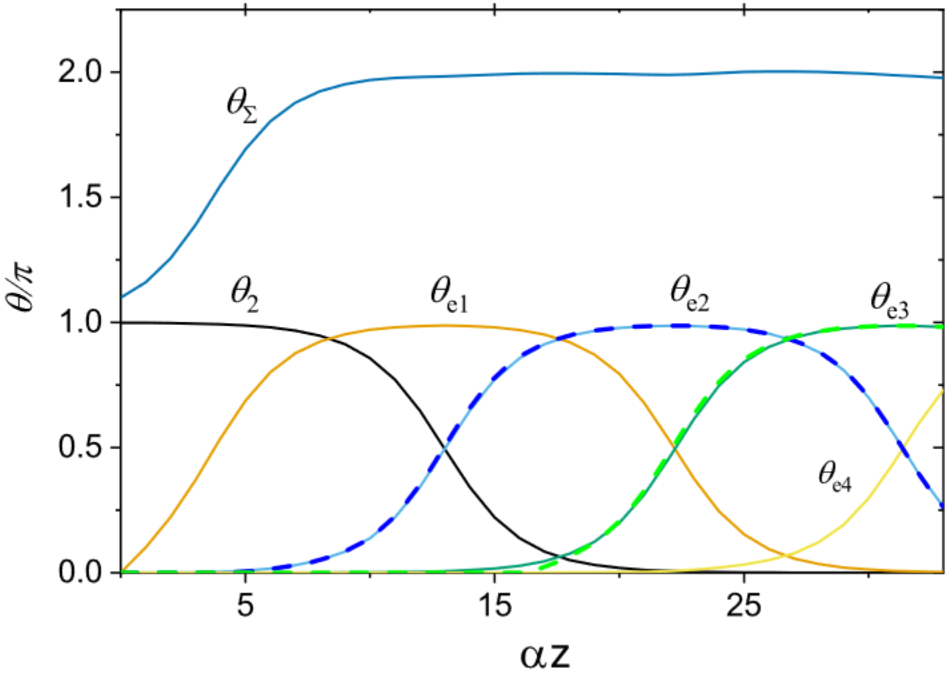


FIG. 2. The multipulse excitation in an optically dense medium. Incoming pulse areas are $\theta_1(0) = 0.1\pi$, $\theta_2(0) = 0.999\pi$. The dashed lines show the approximate solution for the second echo θ_{e2} ($\alpha z_1 = 4.1$; blue dashed line) and the third echo θ_{e3} ($\alpha z_2 = 16.3$; green dashed line).

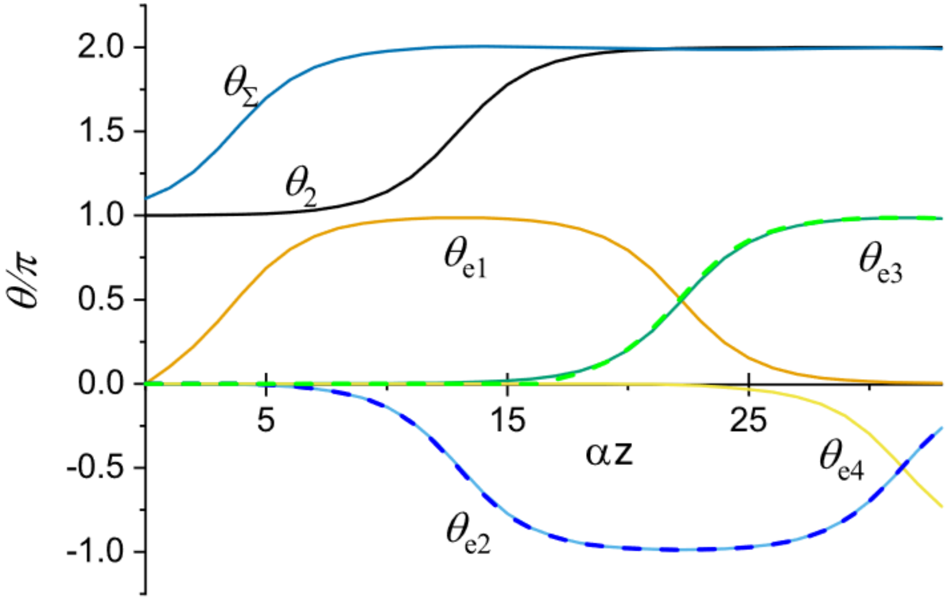


FIG. 3. Evolution of the multipulse excitation in an optically dense medium. Incoming pulse areas are $\theta_1(0) = 0.1\pi$, $\theta_2(0) = 1.001\pi$. The dashed lines show the approximate solution for the second echo θ_{e2} ($\alpha z_1 = 4.1$; blue dashed line) and the third echo θ_{e3} ($\alpha z_2 = 16.3$; green dashed line).

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