Comment on ''Invariance of the spectrum of light on propagation''

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Recently, Wolf pointed out in a series of papers that an important difference can exist between the near-field spectrum $S_Q(\omega)$ and the observed far-field spectrum $S_V(\omega)$ of an extended light source arising from source correlations[1-3] or from correlations between the scatterers.[4] Possible implications for astrophysics, and in particular for the interpretation of spectra of quasars, were pointed out. It is the intention of this Comment to demonstrate that in the relatively new field of localization of light, diffuse secondary light sources are being studied which exhibit precisely those correlations required to show the *Wolf effect.*

Weak localization is the phenomenon which gives rise to enhanced backscattering from a strongly scattering disordered medium.[5,6] The origin of this enhancement comes from constructive interference between time-reversed paths. The enhancement has an angular extension around the direction of backscattering of the order of $\lambda/2\pi\lambda_{\mathrm{mf}}$, λ being the wavelength and λ_{mf} the mean free path of the light. This property implies the existence of a redshift in the scattered light, because the angular extent of the backscattering is wavelength dependent. At a fixed angle the red part of the spectrum is scattered more efficiently than the blue part. This shift is due purely to interference, as the scattering properties of the individual scatterers are assumed to be independent of wavelength. We have derived rigorous integral equations to describe the enhanced backscattering,[7] but as we showed the diffusion approach of Akkermans, Wolf, and Maynard[8] is more than adequate to characterize the phenomena accurately.

A convenient measure for the intensity of the scattered beam is the so-called bistatic coefficient γ. For our purposes it is sufficient to have an accurate expression for the *angular shape* of the enhanced backscattering. I will use the simplified expression of Akkermans, Wolf, and Maynard[8] for the bistatic coefficient of the enhanced backscattering at angle θ_s for a lossless semi-infinite medium $(z>0)$ with an incoming wave at normal incidence:

$$\gamma = 6[1+\tau_0+(1-e^{-2c(1+\tau_0)})/2c]\,, \tag{1}$$

where $c \equiv 2\pi(\lambda_{\mathrm{mf}}/\lambda)|\sin\theta_s|$. To mimic in the diffusion approach some known rigorous results as much as possible, the trapping plane is located slightly outside the real boundary, at $z=-\tau_0\lambda_{\mathrm{mf}}$, $\tau_0 \approx 0.71$. The enhanced backscattering shows very convincingly the Wolf redshift. At a particular angle, the scattered light from an incident beam characterized by a spectral density $S_Q(\omega)$ will be redshifted because longer wavelengths are scattered more strongly as a result of interference of the light from the secondary source. As might have been anticipated the shifts will be rather small unless the spectral width of the incoming light is large. A typical estimate for the fractional redshift $(\equiv\Delta\lambda/\lambda)$ is of the order of 10^{-3} for a fractional linewidth $[\equiv(\mathrm{width})/\lambda]$ of 10^{-1}. It might be interesting to speculate about the possibility of inducing much larger shifts. A promising possibility for this is evidently the case of strong localization.

There are several ways in which the spectrum of light might change even in a linear system. The system acts just as a filter. More or less trivial wavelength-dependent single-particle properties, like Rayleigh scattering and wavelength-dependent absorption, can easily cause such shifts. Wolf has shown that collective interference effects could also act as a filter. The fascinating aspect is that there are no single-particle wavelength-dependent aspects involved. I have shown here that in diffuse light such shifts will be present due to localization effects.

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