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Reply

Reply to Comment on 'Evidence of slow-light effects from rotary drag of structured beams'

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Abstract

The phenomenon of self-pumped slow light, where a single beam appears to be slowed by a solid-state media, is both subtle and controversial. Here, we reply to a comment on our recent work, which uses an observation of enhanced photon drag to distinguish between group delay and pulse reshaping.

Keywords: slow-light propagation, nonlinear optics, structured light beams

It is with interest that we read the comment [1] by Kozlov *et al* on our recent publication in NJP entitled 'Evidence of slow-light effects from rotary drag of structured beams' [2]. The authors appear to agree with our rationale for conducting and reporting the work but not with our interpretation of the results nor our conclusions.

Slow light is a generic term applied to the optical transmission through a variety of physical systems where the speed of light propagation is reduced to far below that normally encountered. One system that has received a far bit of attention is propagation of intense green light through ruby. The first reports of this system featured an intensity-modulated beam, noting

that in the transmitted light the phase of the modulation was consistent with a much reduced group velocity within the medium [3].

Since this first report, it has been argued by some that rather than being a manifestation of slow light, the modification in the phase of the intensity modulation could arise from a simple reshaping of the intensity due to a temporally varying saturation of the absorption (or bleaching) [4]. We agree that these early observations are potentially ambiguous, in that they are possibly consistent with both interpretations [5].

Subsequently we reported an alternative form of the experiment, where the slow-light effect can be observed as a massive increase in the rotational image drag as light is transmitted through a spinning ruby window. But again the observed rotation of the transmitted beam could result either from a reduced group velocity or a spatial reshaping due to a spatial variation of the saturation of the absorption.

As the authors of the comment acknowledge, to address this ambiguity our rational was to deliberately introduce small-scale intensity structure to the beam specifically introducing a line of near-perfect darkness. It is this study that we reported in 'Evidence of slow-light effects from rotary drag of structured beams'. The key question is whether this line of darkness is rotationally dragged by the spinning medium or not. As shown in our original figure 1 and in figure 1 of the comment [1], if the effect is based solely upon a saturation of the absorption then the dark line should exhibit no dragging, whereas if the effect is a reduced group velocity then the dark-line should be dragged by a comparable amount to the bright regions. But what do our results actually show?

In addition to the dragging of both bright and dark regions shown in our original figure 4, our original figure 5 shows exactly the effect that both we and the authors of the comment adopt as the signature for a reduced group velocity. Therefore, we do not agree with the comment that our results 'cannot serve as an evidence of slow-light effects', and we strongly disagree with their statement that our visual representation of our results 'disorient[s] the reader'. Note that the critical intensity notch in their figure 1(b) corresponds to our measured intensity at 90 and 270 degrees in our original figure 5. Of key importance is that the intensity as measured at these positions is increased when the ruby is spun, an effect that cannot be explained with a time varying absorption alone. A simplified version of our original figure 5 is shown below, illustrating the equivalence of our experimental results to figure 1(b) of the comment. We also emphasise that our images and corresponding intensities were spectrally filtered such that they are of the green transmitted light and not the red fluorescence. The darkness of our intensity null is degraded only by scattered light and crosstalk in the camera.

As we discussed in our paper, the logic behind performing these experiments in the spatial rather than temporal domain is that the dark line can be introduced as a phase discontinuity rather than an intensity mask. The π-phase step ensures that the dark line is maintained throughout propagation, whereas the pattern produced as a simple intensity mask is subject to diffractive in-fill. Similarly for an experiment in the temporal domain, a simple intensity step is not necessarily maintained in the presence of a highly dispersive medium.

With respect to the results reported in figure 3 of the comment, we note that their input pulse does not contain an embedded dark line of the type that both they and ourselves discuss in relation to resolving the ambiguity between the two mechanisms (as described in figure 1 of both our original paper and the comment). Whether a sharp change in intensity at the trailing edge of the pulse is equivalent to the dark line in our own experiment is not clear to us. What is clear is that the power level and focussing into the ruby used in the experiment described in the
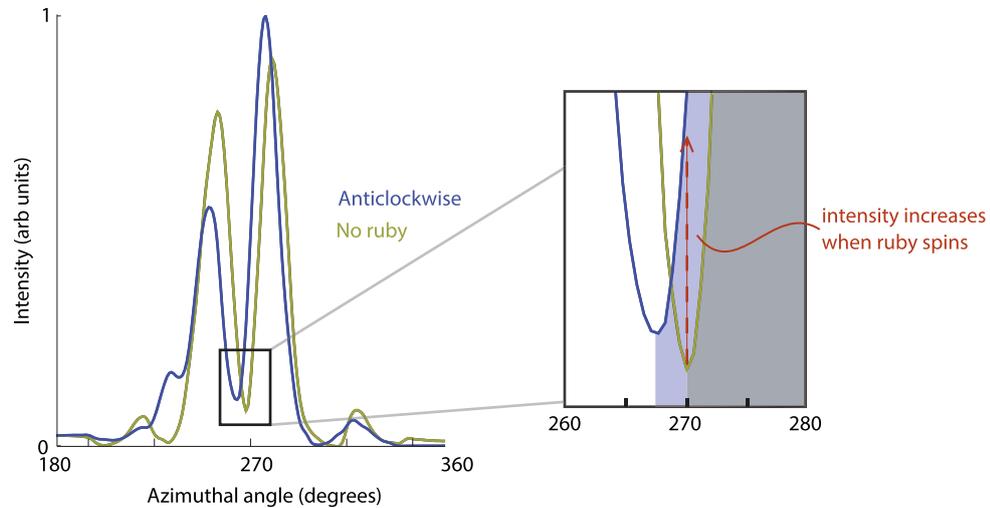
Figure 1. Intensity as a function of azimuthal position. The stopped, no ruby trace (*beige*) has an intensity dip at approximately 270°, whereas in the spinning case (*blue*), the intensity dip has moved to approximately 265° and the intensity at 270° has increased.

comment produce lower intensities than in our own experiments, a factor that we have found essential to observing the image drag that we report. Consequently, we do not see how their latest set of results is incompatible with or undermines our own work.

The difficulties with creating an intensity null in the temporal domain notwithstanding, we are currently undertaking such a study where the input pulse will contain a narrow dark line, and we agree with the authors of the comment that the results will be a further significant contribution to this field.

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