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Comment on "Observation of Superluminal Behaviors in Wave Propagation"

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In their paper [1], Mugnai *et al.* make microwave delay measurements which demonstrate an apparent superluminal propagation of microwaves. We comment on two relevant points: error analysis of the data and the interpretation of the "superluminal results." Mugnai *et al.* show two delay curves, a $v = c$ light line and a $v > c$ superluminal line on a separate plot. Clearly the error bars on each data point (of which there are 11 on the delay plot but only *10* on the error plot) are large enough to span both lines, but no error analysis is given except to show a 99.931% correlation to a straight line for the superluminal data. The authors do not address how good a fit the data are to the light line.

We have reevaluated the Mugnai data extracted from the article error plot in order to find out what the probability is that the superluminal speed exceeds the standard value of c given the total standard error of the mean. Using significance testing statistics, we compared their mean experimental speed of 31.58 cm/ns (10 points) to the standard value of 3.0 cm/ns. We find that there is a 15% probability that the two lines are distinct. That is, there is an 85% probability that the two light-speed lines overlap. The required rms standard error (1.36 cm/ns) was obtained by evaluating the root mean square of the error bars (2.80 cm/ns) about each point together with the standard deviation of the mean (3.30 cm/ns) for 10 points. Clearly, no significant conclusions can be drawn from these exceedingly poor data and the assertion of goodness of fit is largely irrelevant. Regarding the second set of data with better signal-to-noise ratio, the correlation is not even a straight line of differing slope as Eq. (1) of their Letter suggests. The authors tender no explanation, which lends no credence to their superluminal propagation claims.

Referring now to the second point, we note from Ref. [13] in their Letter that the authors have essentially replicated the optical experiment of Saari and Reivelt [2] but using microwaves instead. Their Eq. (1) is the same as that of Saari and Reivelt. Saari and Reivelt, however, clearly state that the X-wave effect they observe, though apparently superluminal, is nothing more than the motion of the intersection of the "axicon-angled" wave front with the Z axis. That is, they are observing a strictly geometric effect. Thus, in Mugnai *et al.*'s experiment, a marked (i.e., modulated) wave front at the axicon angle θ to the Z axis will propagate at that angle, meet its counterpart on the opposite side of the axis, and interfere constructively on the Z axis only: the axis is "lit up"—but only where the impinging waves exist. There are no independent photons that propagate along Z, only along a ray making angle θ with Z; only the intersection of the wave front with Z propagates at speed $c/\cos\theta$ along the axis. Thus, neither energy nor information is propagated at any speed exceeding c. That is because the arrival time of the marker along the light direction at angle θ is the same as the arrival time of the marker along Z. The apparent increased speed along Z compensates for the increased travel distance; that is the nature of "axial waves."

In summary, we feel that the authors have made an inadequate error analysis of their data which does not support true superluminal propagation even though they may have correctly observed the geometric effect indicated above.

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[2] P. Saari and K. Reivelt, Phys. Rev. Lett. **79**, 4135 (1997).

