On the Polarization of Gravitational Waves

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Abstract

It is argued that transversal waves in the geometry of space-time, as postulated by General Relativity, violate translation symmetry within phase planes of a planar wave. Consequently, it is proposed that a corresponding test of transversality is performed, which should have become possible with the increasing number of registered events of gravitational waves. This would provide an independent, new, and essential test of General Relativity.

Remark

A plane wave is characterized by phase planes in which the excitation (a field) is identical within that plane. Thus we have a translation symmetry within a phase plane. This translation symmetry must not only hold for the excitation itself, but also for all measurable quantities derived from it. Clearly, integrals of the excitation, taken along lines within the plane, violate this translation symmetry in general. Such integrals cannot be uniquely measurable quantities, but they are potentials which are only determined up to an arbitrary constant. This is borne out by the dependence of potentials on the origin of integration. An example is the electric potential of a linearly polarized plane electromagnetic wave, which has no absolute meaning but only one given by it's gradient.

This situation is different for the case of gravitational waves of the form postulated by General Relativity [1-3], for which it is claimed that the excitation is a change in the metric tensor. To see that this poses a problem (see also discussion in Ref. 4) we start from a Minkowskian unperturbed situation and take the z-direction as the propagation direction of the plane wave. Now, the position of a test mass in the phase- (x-y-) plane is by itself a potential because we can choose the origin of the x-y-coordinates arbitrarily. If we now consider the change in position of our test mass, caused by the excitation of the wave (change in the metric tensor, constant in the x-y-plane) this is again a quantity with the characteristic of a potential. It is only determined up to two constants and, thus, violates the above stated requirement. More explicitly, for the unperturbed situation the metric tensor yields, on integration in a given direction, positions which have the nature of a potential, They can only be measured after choosing the origin of the coordinate system. Similarly, the change of the metric tensor, constant in x-y-plane at any instant, yields position changes of fixed direction as long as the integration direction is unchanged. The amount of such position changes increases linearly with the integration distance and has, thus, again the nature of a potential. In this generalized sense position changes within a phase plane have the nature of a generalized potential, are not unique, and thus, not measurable. The freedom of choice of the coordinate origin has already been given away in order to make original positions measurable.

It is somewhat difficult not to confuse this latter situation with the freedom of choice of the origin. The problem is most easily illustrated by a commonly used picture to illustrate such waves. This illustration takes test masses arranged in a circle [2, 3]. Under the action of a gravitational wave, the circle is supposed to be squeezed or elongated to an ellipse within the phase plane. This is the result of integrating up changes in the metric (supposedly the primary excitation) along the radial directions from the center of the original circle, which yields the instantaneous new positions. However, the movement of any test point would depend on where we choose the center of the circle to which the point should belong to. A point would not move at all if we chose it to be the center itself. This freedom of choosing a center has nothing to do with the choice of the coordinate origin!

Short Formulation

A prescription which leads to wave excitations that vary within a phase plane violates translation symmetry, and thus, cannot be correct. In our case the true excitations are the position changes and the prescription is the (distance-) line integral modified by the (wave-induced) change in the metric tensor.

Conclusion

The above argument shows that we must abandon the idea of gravitational waves as transversal geometrical ones. One proposed alternative considers the gravitational field as a scalar quantum-field [5-7]. In this case gravitational waves would be longitudinal and the corresponding accelerating field (force) would point along the direction of wave propagation. Such waves obey the required translation symmetry within phase planes.

The detectors for gravitational waves of the LIGO and VIRGO projects are long-baseline Michelson interferometers with the shape of equilateral right triangles designed to optimally probe waves that propagate perpendicular to the triangles, and hence to the surface of the earth [8, 9, 3]. However, they would also respond to longitudinal waves, differently for different propagation directions. The sensitivity would have a directional characteristic different from that of the transversal waves, proposed by General Relativity. In particular, the sensitivity for longitudinal waves vanishes for propagation in a direction perpendicular to the hypotenuse of a detector triangle. The two LIGO detectors have fairly similar sensitivity to transversal polarized waves due to rather similar alignment of the legs of their interferometers. However, for longitudinal waves their sensitivity can be very different for a particular wave, depending on it’s propagation direction. This, because the direction of the hypotenuses of the two detector triangles are nearly perpendicular to each other [8].

There are now several dozen measurements of gravitational wave events and with these it should become possible to perform an analysis of the signal strengths in the light of wave polarization. I’m not aware of such an analysis, but would welcome it very much in the light of the above expressed skepticism. In other words, such an analysis would provide a strong, independent, and essential test of General Relativity. As a caveat, an alert prescription that requires that a signal must be registered in both detectors introduces a bias for this test.

References

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