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Interferometry of uncollimated broadband beams: nifty new things you can do

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We all know how easy it is to interfere laser light, which has great coherence both temporally and spatially. Conversely, for these same reasons it is difficult to interfere ordinary white light, which is broad banded and uncollimated. However, there is great motivation to do so because interferometry is a powerful diagnostic tool, particular for Doppler velocimetry and imaging spectroscopy, and most sources in nature are not laser light.

One can interfere ordinary light if one satisfies both the temporal and spatial aspects of the problem. For the spatial aspect, one trivial solution is to restrict the source extent to a pinhole so that rays out of the desired collimation are discarded. However, this throws away valuable power. A preferred solution, which is a subject of my talk, is to arrange the images associated with the one or more echoes created by the interferometer to superimpose, transversely, longitudinally and in magnitude. Such an interferometer has been called a field compensated or superimposing interferometer. The traditional Michelson and Fabry-Perot interferometers are not superimposing interferometers, but can be made into such by use of virtual or real imaging systems.

For the temporal aspect of the problem, a trivial solution is to restrict the bandwidth to be very small, discarding all wavelengths but a small set. This again has the disadvantage of throwing away valuable power. A preferred solution is to spectrally disperse the light into a large number of channels having small individual bandwidth. A second preferred solution is to use a preparatory interferometer to imprint the light with one or more echoes having the same delay as the second interferometer that will eventually interrogate the light. This preparatory interferometer creates partial coherence in the light, not for all temporal scales, but for the particular scale where it is needed. These two preferred solutions are also subjects of my talk.

I will describe two practical applications of these techniques, as examples, one using the spectrally dispersive method and the other using the preparatory interferometer method. The two examples are called fringing spectroscopy and white light velocimetry[1,2], and they are appropriate for targets that are either self-luminous, or reflective, respectively. Using white light velocimetry the radial velocity of a target was measured interferometrically over an area, the surface being nonuniformly propelled faster at one end than at the other, and in the few meter per second regime useful for industry. The nifty thing is that the illumination was a small ordinary camera flash I borrowed from my girlfriend, and not a bulky laser costing thousands of dollars. In general this technique allows the use of compact inexpensive incoherent sources, where previously they were disallowed due to lack of coherence. Another nifty thing is that the use of white light allows both the range and velocity of an object to be measured precisely. This doesn't violate the uncertainty principle because a new (but harmless) long range ambiguity is created.

The fringing spectroscopy example describes an instrument currently under development, which promises to become a better mousetrap for catching extrasolar planets through the Doppler effect. Whereas current stellar velocimeters are based on the high resolution diffraction grating, in this new instrument the Doppler shift is measured through the fringe shift of a fixed delay interferometer that is spectrally dispersed at low resolution to increase the fringe visibility. The simple instrument response of the interferometer allows a smaller instrumental noise (<1 m/s), which permits the detection of smaller mass planets. The interferometer is also vastly more compact and less expensive. Because the grating that performs the spectral dispersion is not responsible for resolving the Doppler shift, it can be optimized for higher efficiency than that of the high resolution gratings, rather than optimized for accurate point spread function. Furthermore, the low resolution grating allows an instrument etendue which is two orders of magnitude greater than that of current planet hunting spectrometers. This permits multi-object spectroscopy, as well as operation with blurry star images and tolerant wide diameter optical fibers. This further increases effective operational light efficiency. The excess etendue can be used to feed an additional interferometer having a different delay. This allows the lineshape asymmetry to be measured simultaneous to the Doppler shift, the former yielding information on the stellar photosphere dynamics which is relevant to stellar velocimetry in the 1 m/s range. In this latter project I have had the assistance of Jian Ge. The project was supported using Laboratory Directed Research and Development funds under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under Contract W-7405-Eng-48.

References

1. D.J. Erskine and N.C. Holmes, Nature 377, 317-320 (1995).
2. D.J. Erskine and N.C. Holmes, SPIE 2869, 1080-1083 (1997).