SPECKLE INTERFEROMETRY IN ASTROMETRY

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ABSTRACT: Speckle interferometry, which is characterised by diffraction limited resolution and enhanced accuracy, offers a wide range of possibilities for astrometry. Speckle applications are limited by the constraint of isoplanicity with the result that only differential rather than absolute astrometry can be carried out with the technique. Nevertheless, potentially important applications exist in solar system and stellar astrometry, but speckle interferometry has so far made significant contributions only in binary star astrometry.

The role of speckle interferometry in astrometry is essentially limited by the fact that speckle measurements are differential in nature and can only be made over angles within which the perturbing effects of the atmosphere are the same. This so-called isoplanatic angle may be as large as 10-20 arcseconds (Weigelt 1983) but is probably close to 5 arcseconds at most sites at most times. As the isoplanatic limit is exceeded and the speckle patterns from two adjacent stars begin to lose correlation, the precision of astrometric measurements certainly decreases although it is not clear whether systematic effects also begin to enter into measurements. Fortunately the isoplanatic limit is large enough to include a very large sample of double stars but too small to reasonably expect to gather together a reference frame for parallax and proper motion studies. With these restrictions in mind, one can list the following limiting capabilities of speckle interferometry:

Resolution	0''020
Magnitude	17
Δm	5
Precision	0''0001

The limiting resolution is a straightforward result from the fact that the largest coherent optical telescope has an aperture of 6 meters

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with a Rayleigh limit of about 0".020. The limiting magnitude is based upon theoretical considerations (Dainty 1974) and observational experience (Hege et al. 1981; Meaburn et al. 1982), but it is rather unlikely that routine astrometric programs involving many stars can afford the large amounts of telescope and analysis time needed to go as faint as magnitude 17. A routine limiting magnitude of +13 is far more reasonable and permits the expansion of existing programs (which are already near saturation) to nearby low luminosity objects in the case of stellar astrometry or to a significant sample of minor planets for solar system work. A limiting magnitude difference of 5 magnitudes is also a bit of a guess; the companion of μ Cas ($\Delta m = 5$) has not yet been detected in the visible by speckle interferometry, but the companion to 85 Peg ($\Delta m = 3$) can be detected without too much difficulty.

Of great interest in astrometric applications is the limiting precision with which angular measures can be obtained by speckle interferometry. The enhanced precision of speckle interferometry over standard astrometry is, in essence, that with speckle one is measuring the location of an autocorrelation peak with a diameter of perhaps 0".030 whereas in photographic astrometry one is centroiding on a seeing-averaged image perhaps 100 times larger in diameter. A precision of ± 0".0001 is based upon sampling across a 0".030 diameter speckle with six pixels and achieving centroiding to within 2% of a pixel size. Tests are currently underway at Georgia State University to evaluate this limiting precision, a critically important parameter in our program aimed at detecting low mass companions within wide binary star systems.

Speckle applications in solar system astrometry are rather limited due to the isoplanicity constraint. The only dynamical study that presently has benefited from speckle is the analysis of the Pluto/Charon system, and measurements have been obtained by two groups of observers (Bonneau and Foy 1980; Hege et al. 1982). An orbit for the system based entirely on speckle observations without reference to the astrometric orbit of Harrington and Christy (1981) remains to be done.

Other possible solar system applications involve minor planets and the presently suggestive although not compelling evidence for their duplicity. This evidence exists in the form of light curves, occultation timings and, in the cases of 2 Pallas and 12 Victoria (Hege et al. 1980) and 532 Herculina (Drummond and Hege 1983), speckle observations. No conclusion entirely unambiguous from albedo or elongation effects yet exists to answer the intriguing question of minor planet duplicity, but speckle interferometry is probably the most powerful approach to the problem.

During occultations of stars by minor planets, speckle observations have the potential for determining accurate geometry for the event. Such information is important in placing a limit on the diameter of the occulting body in the case of a near miss or, of greater value, in determining the precise cords traced out during an occultation observed from one or more places. This is an area in which speckle interferometry on intermediate sized telescopes can be especially useful.

Speckle interferometry is currently unrivaled in a diversity of applications to stellar astrometry. These applications include binary stars, globular cluster internal motions, detection of extrasolar planets in wide binaries, structure of extragalactic reference objects and the support of Space Telescope and Hipparcos astrometry. The measurement of double stars has by far been the most productive area in astrometry to which speckle has contributed, and a summary of these accomplishments will be saved for the end of this paper.

Experience has shown that globular cluster cores exhibit large enough numbers of bright stars with paired spacings within the isoplanatic patch so that the "binary star" approach to these objects can set up a tightly configured frame in which relative positions accurate to better than 0".001 can be established. This is an order of magnitude gain over photographic astrometry and describes a sample of objects excluded due to overcrowding from standard proper motion studies. It is hoped that a project of this nature can begin with the GSU speckle camera during 1984-85.

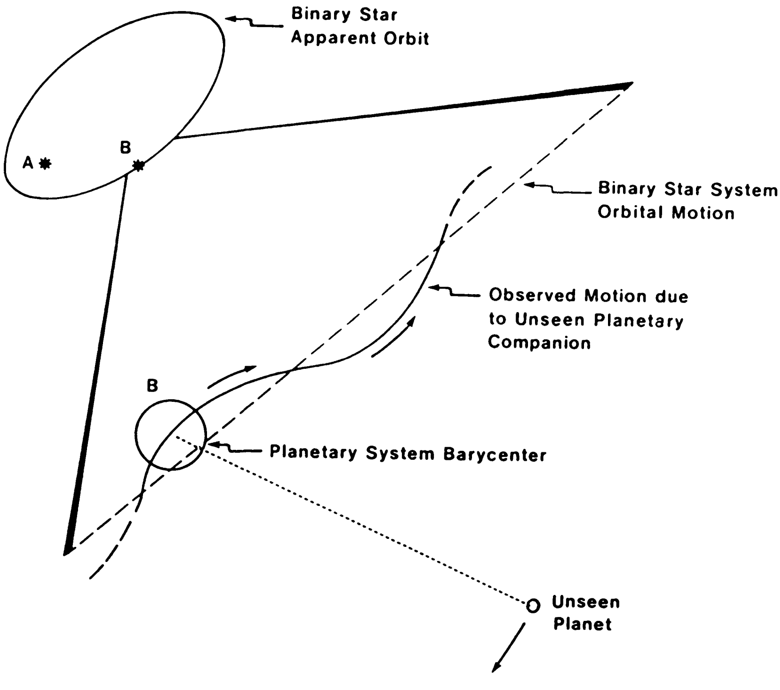

Figure 1. A schematic representation of the effect of a planetary mass companion around one component of a wide binary star system.

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Another area in which speckle can uniquely contribute is the search for low mass companions in visual binary systems (McAlister 1977). Figure 1. schematically demonstrates that the approach is identical to the astrometric procedures used for decades but is applied to a class of objects inaccessible to other techniques because of either image or spectral line blending. A long-term collaborative program between GSU and Lowell Observatory has been underway since 1981 with support from the U.S. Air Force Office of Scientific Research. This program involves monthly observation with the 72-inch Perkins telescope and the GSU ICCD speckle camera of a sample of some 100 binary stars having separations in the range of 0".2 to 3".0 and distances less than 25 pc. The observing list is sufficiently large to include a meaningful sample of stars and sufficiently small to permit the frequency of observation needed to obtain a precision of 0".0001. To guard against possible systematic effects, the observing list also includes another 150 or so reference and standard stars. Sufficient data has now been collected for a study to be completed during 1984, of the attainable accuracy in our program.

Speckle interferometry can play an important support role in absolute astrometry by searching for duplicity among objects used as reference or tie-in sources in large-scale astrometry programs. It is important that extragalactic objects used to tie visual to radio reference frames be simple point sources, and speckle observations can be used to ensure that astrometrically unresolved and photometrically variable structures are not causing photocentric shifts in the images of these objects. Similarly, guide stars for Space Telescope which turn out to be close binaries can be particularly troublesome to achieving repeatable and accurate offsets to program objects. The GSU speckle camera is currently being used at Flagstaff to survey for duplicity a sample of reference stars which will tie the Space Telescope and Hipparcos reference frames together.

The application of speckle interferometry to binary star astrometry has been recently reviewed elsewhere (McAlister 1983) and only a brief progress report will be presented here. A catalog containing all binary star speckle measurements published through the end of 1983 has been compiled by McAlister and Hartkopf (1984) and is available at no cost from the authors. There are approximately 3300 speckle measurements of some 800 systems available for accurate orbital analyses. These measures have a mean separation of 0".32 and a median value of 0".21. Twenty percent of the measures are of separations less than 0".10 while fewer than 5% exceed 1".0. Measured separations range from 0".026 to 4".1 and thus encompass what was once the exclusive domain of visual micrometry. Speckle results are routinely accurate to within ±0".002 or better depending upon the aperture of the telescope and the type of calibration procedure carried out by the particular observers.

Calibration remains a critically important area in speckle interferometry and generally concerns two distinct sources of systematic error: the spatial scale of the telescope/camera system and the effects of seeing upon the power spectrum or autocorrelogram from which the binary star measurement is obtained. The scale calibration can be obtained rather simply by mounting a double slit mask at the entrance pupil, or an intermediate pupil, to the telescope and determining the angular frequency of the resulting fringes. Calibration for seeing is unfortunately not so straightforward since everything changes when moving from a program object to a point reference object, and it is probably safe to say that a perfect seeing calibration is not possible to achieve. One approach to this problem is discussed in the following paper at this symposium. As an aid to calibration, although not intended as a substitution for it, and as a means for intercomparing results from various observers, a list of standard stars for binary star interferometry has been published (McAlister and Hartkopf 1983).

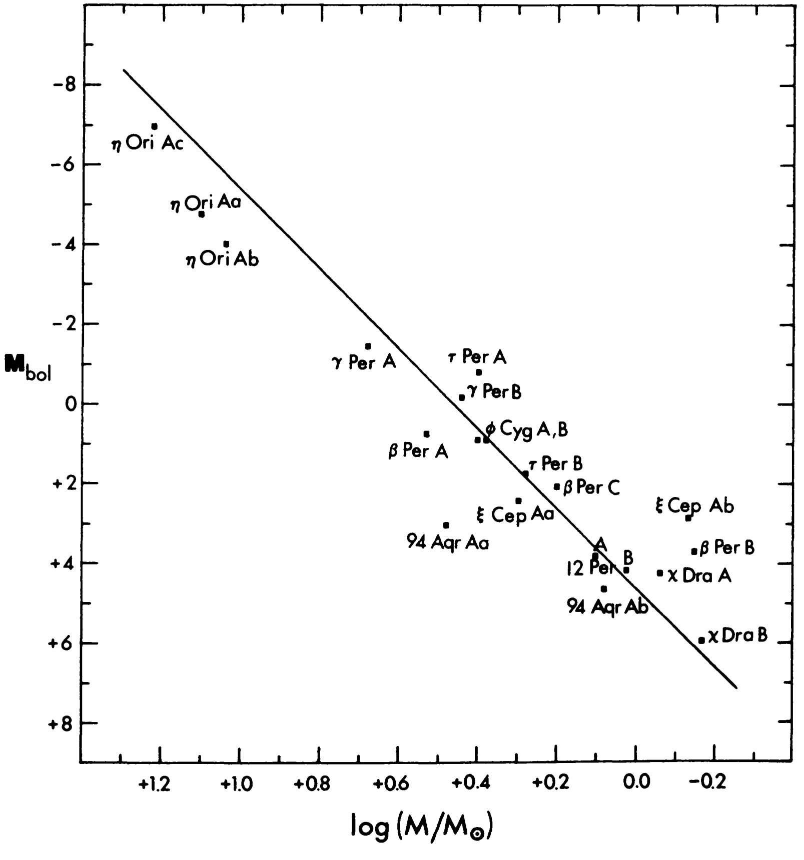

Figure 2. The contribution of speckle interferometry to the mass/luminosity relation. Complete references to the individual system analyses can be found in the catalog of McAlister and Hartkopf (1984).

Speckle interferometry has reached maturity as a useful tool for binary star astrometry. Through the direct resolution of spectroscopic binaries, speckle has added new points to the empirical mass/luminosity for stars as is shown in Figure 2. Many more points will be added as observations of some 40 resolved spectroscopic binaries continue and particularly as improved parallaxes are available from the Hipparcos satellite. The prospects for highly accurate parallaxes from space make interferometric observations of binary stars especially important in the coming decade. Speckle observations of one of the many systems for which masses will then be available are shown in Figure 3. Eta Virginis consists of a spectroscopic system with a period of 70 days and a third component seen in the speckle measurements of components AB,C. There is some indication that the submotion of components AB is represented in the speckle observations, but it is premature for a meaningful analysis. The Eta Virginis system is classified as spectral type A2 IV.

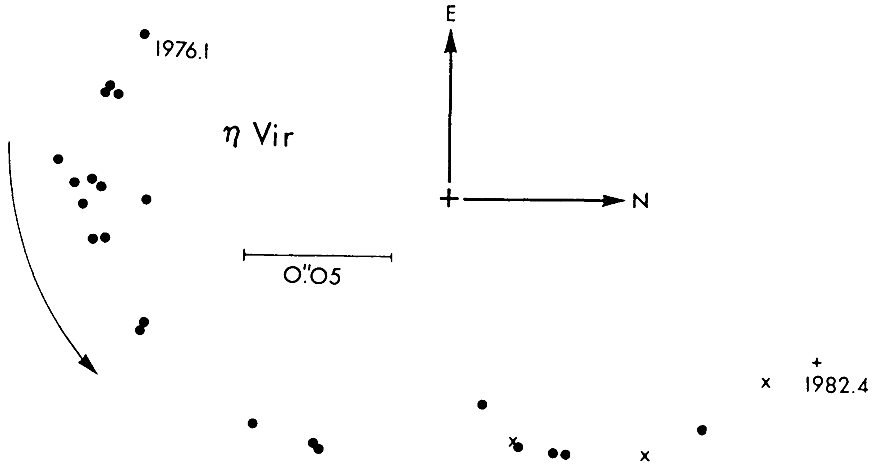

Figure 3. Speckle observations of Eta Virginis AB,C are leading to an accurately determined relative orbit in which the submotion due to AB may be detectable.

Speckle interferometry is a proven technique for performing highly accurate, differential astrometry of very small fields. Only a handful of groups throughout the world are active in speckle work, and astrometry usually takes second priority behind the more astrophysically oriented goals of these groups. Nevertheless we can expect astrometry to continue to benefit from speckle observations especially in areas in which no other technique can presently compete.

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REFERENCES

Bonneau, D., and Foy, R. 1980. Astron. Astrophys. 92, L1.
Dainty, J.C. 1974. Mon. Not. Royal Astron. Soc. 169, p. 631.
Drummond, J.D., and Hege, E.K. 1983. Bull. Am. Astron. Soc. 15, p. 823.
Harrington, R.S., and Christy, J.W. 1981. Astron. J. 86, p. 442.
Hege, E.K., Cocke, W.J., Hubbard, E.N., Christou, J., and Radick, R. 1980. Bull. Am. Astron. Soc. 12, p. 662.
Hege, E.K., Hubbard, E.N., Strittmatter, P.A., and Worden, S.P. 1981. Astrophys. J. 248, L1.
Hege, E.K., Hubbard, E.N., Drummond, J.D., Strittmatter, P.A., Worden, S.P., and Lauer, T. 1982. Icarus, 50, p. 72.
McAlister, H.A. 1977. Icarus, 30, p. 789.
McAlister, H.A. 1983. I.A.U. Colloquium 62 on Current Techniques in Double and Multiple Star Research, R.S. Harrington and O.G. Franz, editors, Lowell Observatory Bull. No. 167, Vol. IX, No. 1, p. 125.
McAlister, H.A., and Hartkopf, W.I. 1983. Pub. Astron. Soc. Pac. 95, p. 778.
McAlister, H.A., and Hartkopf, W.I. 1984. Catalog of Interferometric Measurements of Binary Stars, Georgia State University Center for High Angular Resolution Astronomy Contribution No. 1.
Meaburn, J., Morgan, B.L., Vine, H., and Pedlar, A. 1982. Nature, 296, p. 331.
Weigelt, G. 1983. I.A.U. Colloquium 62 on Current Techniques in Double and Multiple Star Research, R.S. Harrington and O.G. Franz, editors, Lowell Observatory Bull. No. 167, Vol. IX, No. 1, p. 144.

Discussion:

HEMENWAY: We're planning to use Space Telescope to tie the HIPPARCOS System to QSO's. What are the prospects of actually using the speckle techniques to map the brightest distribution of 16th magnitude QSO's?

McALISTER: This is a reasonable project. The greatest difficulty would be to be allotted time at Kitt Peak. 17th magnitude, however, might be very time consuming.

de VEGT: Is it possible to extend the magnitude limit from 17^m to 19^m? Most extragalactic sources suitable for the extragalactic reference frame are fainter than 17^m.

McALISTER: I think one could do that - with a photon limited system one just needs to take more data, but eventually one reaches a point where millions of frames must be taken and this is very uneconomical with regard to telescope time, but could be done.

HEMENWAY: What happens when you go to a 7 meter telescope?

McALISTER: I don't think much is gained by going to a larger telescope. The biggest gain would be in precision due to the smaller resolution limit.

WARREN: How time consuming, in terms of human labor and computer time, is the reduction of your speckle observation? You have reported that many binary observations were made. We know that you have published some of these, but have you completed a list of all of the results that might be published or circulated?

McALISTER: This is a labor intensive undertaking. With a photographic system there was a delay between data acquisition and analysis. We are aiming at a real-time system. The new system increases efficiency by about two orders of magnitude. We are now in the process of compiling a catalogue of observations and publishing it, including the negative results. I will be happy to furnish pre-publication copies on request.