THE PROMISE OF OPTICAL/IR INTERFEROMETRY AND SPACE ASTROMETRY

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Referring to the "promise" of something is likely to imply that little has been accomplished. This is not true in the present case however. In optical interferometry, for example, there has been a steady development during the last decade or so after somewhat of a lapse subsequent to Michelson and Pease's work some 65 years ago. Most of the work to date, however, has been directed towards the measurement of stellar diameters and binary stars and is hence not germane to the present topic of reference frames. What is required for the latter is the analog of the phase coherent interferometers used with such conspicuous success in radio interferometry. The important point is that such analogs are now available in both the optical and infrared (10 μ) wavelength regions.

Regarding the optical case, the first measurements of large angle stellar positions have been made with the Mark II instrument of Shao [1]. Without giving details of the instrument, the fringe tracking ability of the Mark II is shown by the raw data plot in Figure 1. It also illustrates the ability of this instrument to shift sequentially between stars. The latter attribute is important for large angle astrometric work. This wide band instrument uses direct detection with an optical delay line to maintain near equality of path in the two legs of the interferometer. Equality is essential if the central, white light fringe is to be tracked. Figure 2 shows a plot of the red pass band phase vs. the blue pass band phase. If the central fringe is indeed being tracked this plot should indicate a near zero mean fluctuation. This is usually the case, as shown by the points lying near the center of the plot, but if a first order fringe is inadvertently tracked it is easily detected by the existence of points such as those lying to the left in Figure 2. The size of the collecting apertures of such an optical interferometer is limited by the spatial coherence of the atmosphere at optical frequencies to about 10 cm. in diameter. Similarly, temporal coherence times of the order of .01 second require that fast sampling be used. These effects limit the observable magnitude to about 10 for an earth based, photon limited interferometer. A more realistic limit might be around 8th magnitude. A tremendous amount of first class reference frame work can be accomplished within these limits.

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The reduction of the data from the Mark II indicated a modest precision of an arc-second or so. Considering the experimental nature of that instrument, particularly as regards thermal and mechanical variations, this precision is explicable and acceptable. The forthcoming Mark III instrument incorporates many refinements and improvements. Initial work with this instrument should give precisions of about 0."01 with extension to 0."001 reasonably attainable. The important point is that the basic "promise" has become fact. The proof of principle is in hand, and we are now building a much improved instrument based upon this proven approach. Some additional details will be given at the Commission 8 meeting during Session No. 1 on 27 November.

Although less interferometric work has been done historically in the mid-IR region, here too remarkable progress has been made. Just as in the optical case the essential principle has been successfully demonstrated. As predicted by theory, diffraction limited performance of IR systems has been found to be permitted by the atmosphere at much larger apertures, (perhaps two to three meters) than in the optical case. The coherence time of the atmosphere scales with wavelength in the same way. The work by Townes [2] should be consulted for the details of astrometric infrared interferometry. Here, I wish to stress that, just as in the optical case, fringes have been successfully tracked. Indeed, plots of raw data similar to that shown in the optical case have been obtained by instrumentation which was much less than ideal. Nevertheless, large angles between stars have been measured with night to night repeatabilities approaching 0."01 even with equipment never intended for precision work. In short, the method works. This has led to the development of an infrared interferometer which can easily produce astrometric data at the 0."01 and level beyond. In this narrow band instrument, heterodyne techniques are used exactly as in radio interferometry but using a CO_2 laser as the local oscillator. It is also feasible to construct a delay line and use direct detection in order to increase sensitivity. It may not be realized, however, that even using heterodyne methods it is possible to detect hundreds of FK5 stars with the instrument currently under construction.

Of course, the nemesis of ground-based imaging astrometry, the atmosphere, causes problems with interferometric measurements as well. In the case of the optical interfermeter the delay lines are in vacuum thus measuring the vacuum path difference directly. In addition, two color bands are used to remove the non-compensated path length differences introduced by, for example, atmospheric wedges. Since the dispersion curve of the atmosphere near the 10μ atmospheric window is essentially flat, multi-color techniques are less useful in the infrared case. On the other hand, the indices of refraction for dry air and water vapor are virtually identical in this wavelength region making the IR instrument insensitive to the atmospheric composition. Thus IR measurements at various zenith distances may be able to, for example, sample various wedge effects and successfully eliminate them. It appears that atmospheric effects in both optical and infrared astrometry are manageable at high precisions as they are susceptible to various measuring, modeling and sampling techniques.

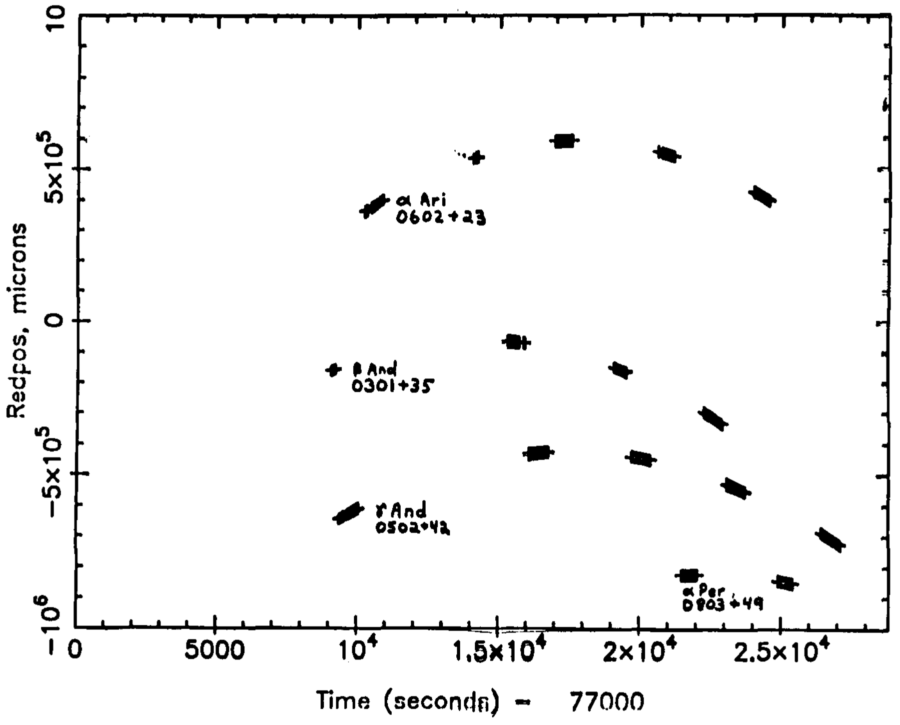

Figure 1

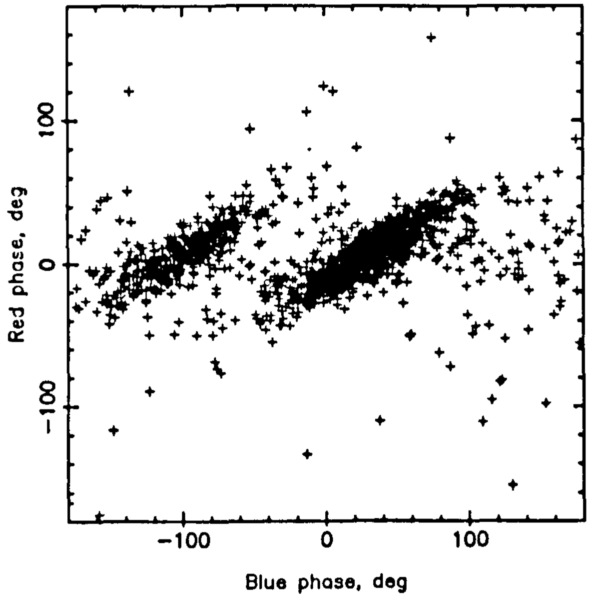

Figure 2

Thousands of traditional "astrometric" stars, which have defined our reference frame, are observable by both optical and IR interferometers. A unique opportunity is thus available to examine systematic effects at the milliarcsecond level. This may be the most important artifact of the new systems since, if limited by precision alone, even the classical transit circle systems would have reached this level long ago.

In the case of space astrometry we are all, of course, eagerly awaiting the results of HIPPARCOS and the HST. As already outlined, a major contribution to the improvement of existing global reference frames is anticipated. Of course, space ventures are extremely expensive and, perhaps even more to the point, extremely competitive. For this reason, one cannot count upon future space astrometry which will be particularly useful for global reference frames, but on the other hand, the community must aggressively present reasonable, ongoing proposals in order to capitalize on any opportunities which may present themselves.

At the moment, two possibilities suggest themselves in the optical case. First, an imaging telescope with a 1 meter class aperture, capable of observing extragalactic sources, perhaps to 19th magnitude with a large dynamic range, can define "local," QSO based reference frames. Such local (small field) frames are useful in proper motion work. If then in addition, these local frames could be related one to another, a global frame could be constructed. One possibility, which could provide this capability, is the use of very precise gyro systems. Such devices approach proportional errors near 10^{-7} and of course could be "re-set" with respect to some agreed upon set of extragalactic references. One might consider a hybrid system involving mechanical and fiber optic gyros. Although probably limited at the present time to something of the order of 0"01, such an arrangement does have the potential of riding "piggy back" on <u>any</u> astrometric mission involving suitable target objects regardless of the primary motivation of the mission. Precision gyros may well be required in any event for the orientation of a field containing but one QSO in proper motion work. By using the best available gyros rather than "nominal" devices, the astrometric return would be increased.

A second, potentially more precise approach, involves the use of a double optical interferometer in space. In this case, one would make measurements like those made by HIPPARCOS, but with the increased precision of the interferometric technique. Such a device, observing extragalactic references directly, would be the most promising method envisioned.

Progress continues in all these areas, both conceptually and in the concrete realization of systems. The promises are being kept.

<u>References</u>

Shao, M., Present Status and Future Plans for the 2 Color Astrometric Interferometer Project., IAU Sym. 109, Gainesville, FL.
Townes, C.H., Spatial Interferometry in the Mid-Infrared Region, J. Astrophys. Astr. (1984)<u>5</u>, 111-130.