SOURCE STRUCTURE CORRECTIONS TO THE GEODETIC VERY LONG BASELINE INTERFEROMETRY OBSERVABLES

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This paper will attempt to address two questions: (1) why does source structure affect very long baseline interferometry (VLBI) observations at all, and (2) how does source structure corrupt the geodetic observables? Then, finally, evidence will be presented which shows that corrections for source structure are possible and necessary for centimeter-level accuracy VLBI measurements.

Why does structure affect VLBI observations? How is it possible to determine this structure? Before considering more complex sources, let us first review the response of an interferometer to a point source. In this case, the received signal can be considered to contain two parts, (1) noise from the source which will be identical at the two antennas (see figure 1), and (2) the receiver noise, etc., which is independent at the two antennas. Thus, when the signals from the two antennas are correlated, the peak of the amplitude of the correlation function is proportional to the ratio of the system power due to the source to the total system power, independent of the observing geometry:

$$|\rho| \propto \frac{P_{source}}{P_{total}}$$

Unfortunately, nature was not generous enough to supply point sources useful for geodetic applications, and we are forced to consider more complex situations.

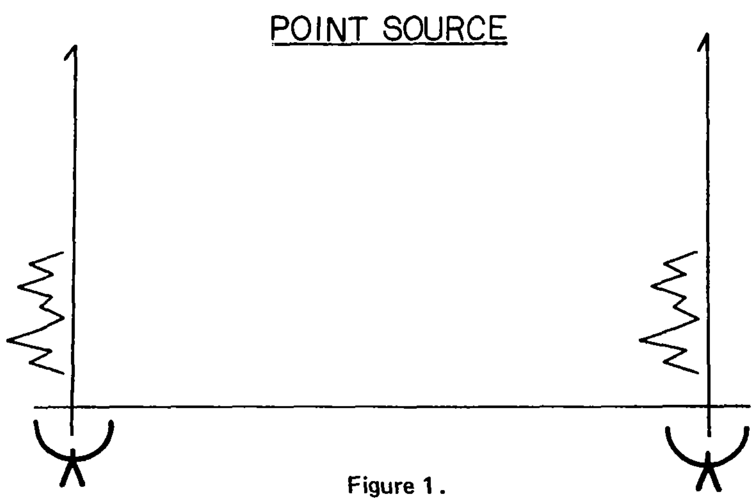

Figure 1.

The simplest possible extended source is an equal brightness double point source, which will be sufficient to show the general features of extended structure. In this case, the signal from each component is still identical at the two antennas but with different delays. This is demonstrated in figure 2 on a greatly exaggerated scale. The delay difference causes the two patterns to interfere, reducing the observed correlation amplitude. In this case, the correlation amplitude is of the form:

$$|\rho| \propto \frac{P_{source}}{P_{total}} \cos(2\pi\nu\Delta\tau)$$

where ν = the observing frequency. The delay difference depends on the observing geometry so the observed correlation amplitude will be different on different baselines and vary with time on a given baseline.

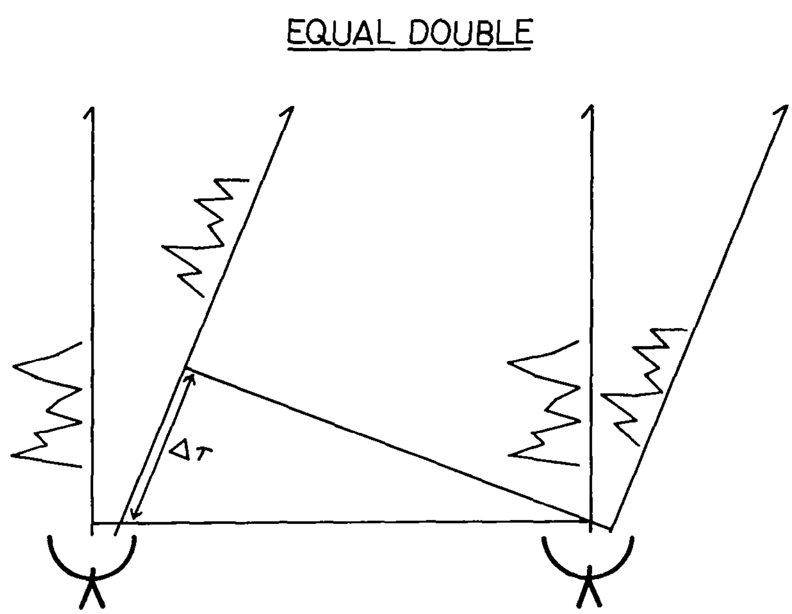

Figure 2.

In the most general case, the observed correlation function is proportional to the so-called visibility function which is the Fourier transform of the source brightness distribution:

$$\rho \propto V(u,v) = \int\int B(x,y) \exp[-2\pi i(ux + vy)]\, dxdy$$

where B(x,y) is the brightness distribution. Note that the visibility is complex as this point will be relevant to the following discussion. It is possible to deduce the source structure if a sufficient number of observations of the correlation function are made and properly calibrated. (See Cotton, 1979, Astron. J., 84, 1122.)

The second question posed at the beginning of the paper was what effect does source structure have on the geodetic observables, group delay, and fringe rate. The group delay is defined as the derivative of fringe phase with respect to angular frequency:

$$\tau = \frac{d\phi}{d\omega}.$$

Since the visibility, or structure phase, can vary arbitrarily rapidly with observing frequency, especially near amplitude minima, the measured group delay can be affected to an arbitrary degree. Extreme cases of this phenomenon are easily detectable because of the very pronounced minimum in the observed correlation amplitude. The structure contribution to the observed group delay is given by the following relationship:

$$\tau_s = \frac{\mathrm{Re}(V)\,\frac{d\mathrm{Im}(V)}{d\omega} - \mathrm{Im}(V)\,\frac{d\mathrm{Re}(V)}{d\omega}}{|V|^2}.$$

Likewise, the contribution of the source structure to the observed fringe rate is given by:

$$\dot{\phi}_s = \frac{\left[\mathrm{Re}(V)\,\frac{\partial \mathrm{Im}(V)}{\partial u} - \mathrm{Im}(V)\,\frac{\partial \mathrm{Re}(V)}{\partial u}\right]\frac{du}{dt}}{|V|^2} + \frac{\left[\mathrm{Re}(V)\,\frac{\partial \mathrm{Im}(V)}{\partial v} - \mathrm{Im}(V)\,\frac{\partial \mathrm{Re}(V)}{\partial v}\right]\frac{dv}{dt}}{|V|^2}.$$

Nature has added a further complication; that is, that many sources have time variable structure. This has two effects: (1) the corrections to group delay and fringe rate are time variable and (2) the apparent position of the source can change. To resolve these difficulties, we need to monitor the source structure and to pick, on physical grounds, a feature in the source which is most likely to be at a constant position in the sky.

The bottom line of this paper is, of course, how much effect does source structure really have? To address this question, figure 4 shows the effects due to the structure of 3C 345 on observations on the Goldstone-Sweden baseline in May 1974. The map of 3C 345 used is shown in figure 3. The reference feature for this source is the component on the left which has had a relatively constant brightness and size for the last few years and is probably fixed in the nucleus of the parent object.

In figure 4, the corrections to the delay and rate as well as the visibility amplitude and phase are plotted as a function of Greenwich Sidereal Time. Figure 4 indicates that corrections to individual delay observations can be many centimeters, especially near minima in the visibility amplitude.

In order to avoid giving the impression that the problem is always this severe, figure 5 shows perhaps a more nearly typical case, Haystack-Goldstone, for the same source and epoch in which the maximum corrections are only a few centimeters. Since geodetic measurements involve a number of

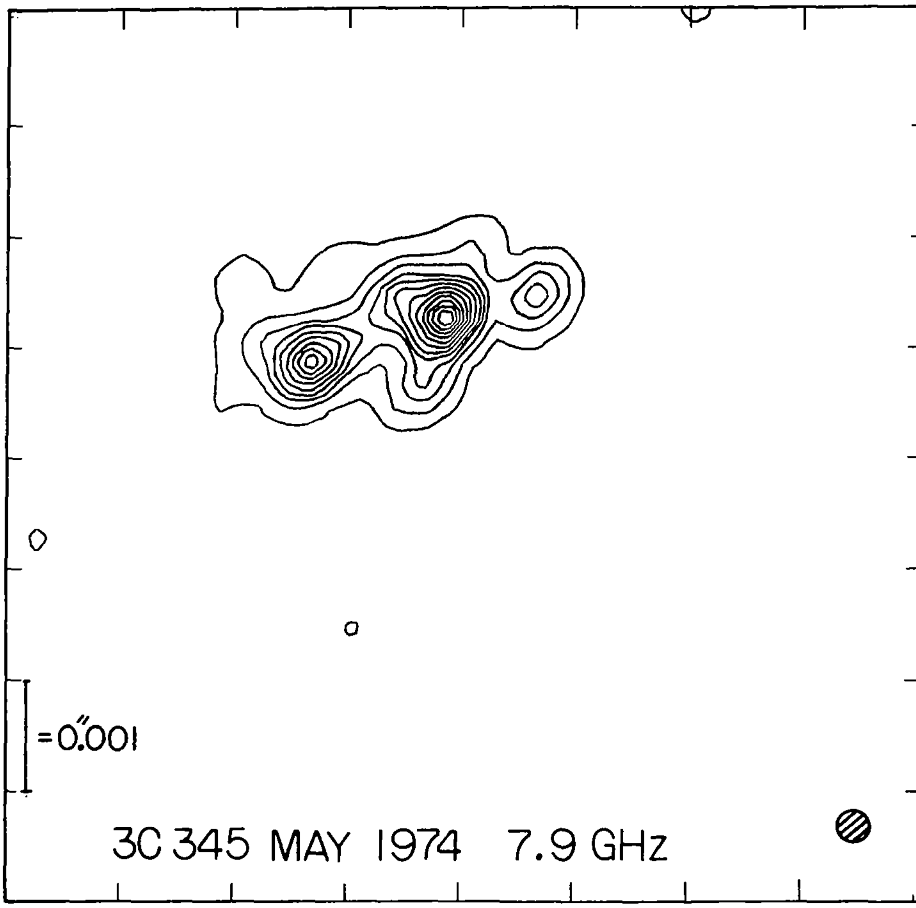

Figure 3.

sources, the effects of structure on the final results will be somewhat diluted. While we have not performed conclusive tests, we feel that structure has probably not had a serious effect on results to date. However, if the full potential of the Mark III system is to be realized, source structure corrections must be made.

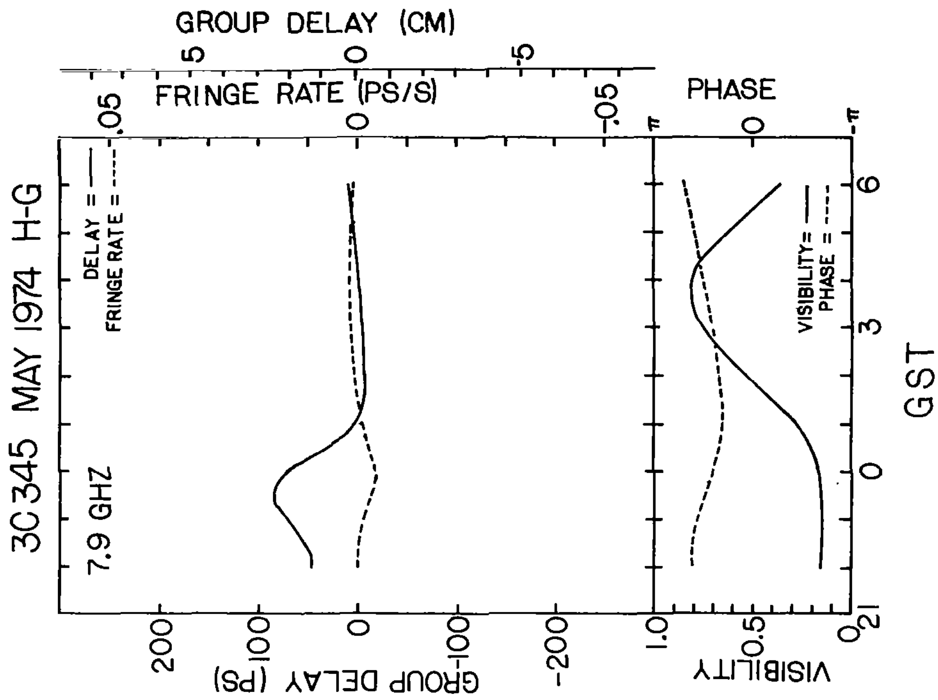

Figure 5.

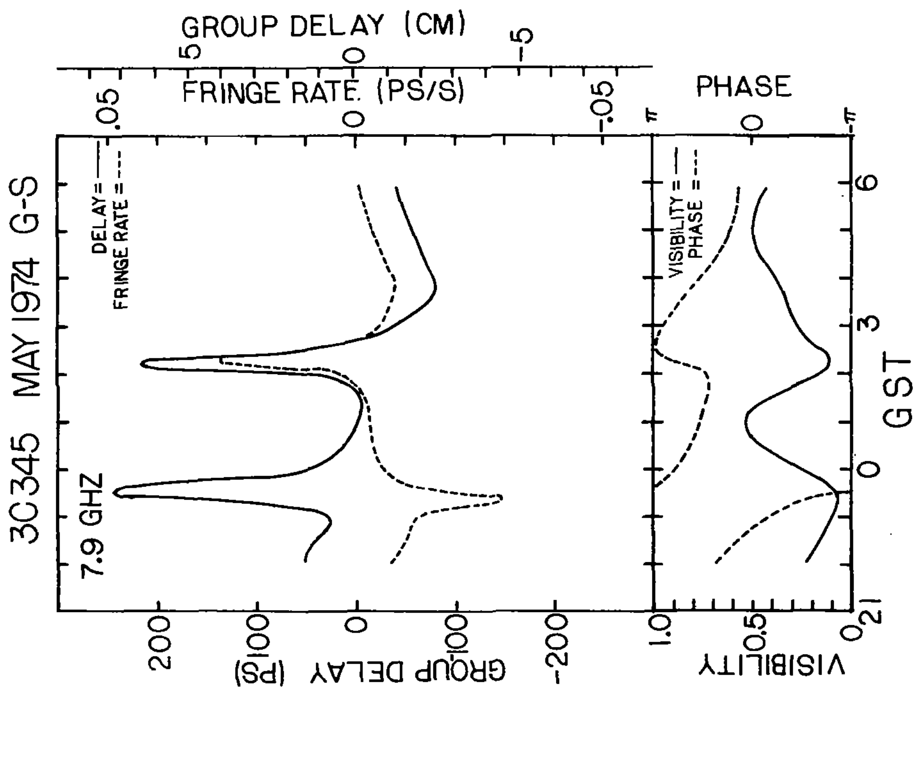

Figure 4.