Binary Star Astrometry and Photometry from Transfer-Function Scans with *HST* FGS3: Calibration, Stability, Precision, and Accuracy

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Abstract

We illustrate the concept of binary-star astrometry and photometry based upon observations with the Hubble Space Telescope Fine Guidance Sensors (FGS) in the Transfer Function (TF) Scan mode. Using data obtained over an 18-month interval in 1992-1993, we assess temporal TF stability and examine its significance for binary-star investigations by FGS transfer-function analysis. We present astrometric results for Cycle-2 scale-calibration binaries observed with FGS3. Analysis of multiple observations indicates a precision of 1 mas. We compare the measured relative component-positions with ephemeris values from orbits based upon extensive series of speckle observations. This comparison shows that the accuracy of binary-star astrometry with FGS3 in the TF-Scan mode is 1 mas.

I. Concept of Binary-Star Measurement by *HST* FGS Transfer Function Analysis

We assume the Transfer Function (TF) of a resolved binary star to be a linear superposition of two single-star functions. If $F(X)$ is the TF of a single star on the FGS X-axis, a double star will thus yield a TF of the form,

$$D(X) = A \times F(X + Z) + B \times F(X + Z + S)$$

where, A and B are the fractional intensities of the binary components, Z is a zero point offset, and S is the component-separation along the FGS X-axis. An equivalent expression exists in FGS-Y.

This concept is illustrated in Fig. 1 with data for ADS 11300 (= Hu 581 = WDS 18229+1458 (2000)), a visual binary of magnitude 8.3 and angular separation near 0.1 arcsec.

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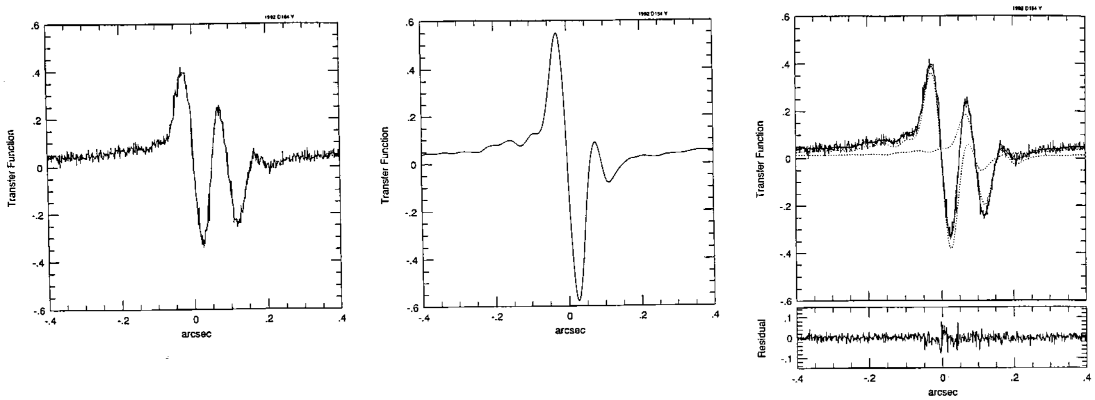

Figure 1: A sample Transfer Function (TF) of ADS 11300 (left) obtained on 1992 day 154 shows the binary well resolved on the FGS Y-axis. A smoothed single-star TF (middle) derived by co-addition of several de-jittered scans is used in the binary-star data analysis. The result of the analysis (right) is illustrated by a computed curve (smooth solid line) representing the best-fitting linear superposition of two single-star TFs (dotted lines). Residuals show no systematic differences between observed and computed binary-star TF.

II. Transfer Function Stability

Because analysis of binary-star scans obtained with the FGS requires accurate knowledge of the single-star Transfer Function (TF), it would be best to obtain such calibration data contemporaneously with every binary-star observation. However, this approach is not only costly in observing time, but also vulnerable to observational failures. It is thus important to examine the temporal TF-stability and to determine whether archival single-star data can be used without degradation of binary-star photometry and astrometry.

To assess temporal TF-stability and its significance for binary-star investigations, we have used single-star (Upgren 69) data from six separate dates over an 18-month interval in 1992-1993 to analyze TFs of ADS 11300 obtained on 1993 day 92. All scans were made near the center of the field of view (FOV) of FGS3. The values so derived for the angular separations of the binary components in X, Y, and for the magnitude difference are presented in Table I.

Table 1: Astrometric and Photometric Results for ADS 11300 from Observations of 1993 day 92 Analyzed with the Use of Single-Star Data, Both Contemporaneous and from Different Dates

single-star date		angular separation (arcsec)		mag. diff.
(year)	(day)	X	Y	
1992	049	–0.093	0.054	0.68
	098	–0.093	0.055	0.68
	154	–0.093	0.054	0.66
	245	–0.093	0.055	0.67
1993	*092*	*–0.093*	*0.054*	*0.69*
	217	–0.092	0.055	0.65

The small scatter of the tabulated values of angular separations and magnitude difference indicates remarkable stability of the single-star TFs from the six widely separated dates. It must be noted, however, that susceptibility of the analysis to effects of Transfer Function variations will grow with decreasing angular separation and increasing magnitude difference of the binary components.

III. Scale Calibration: Astrometric Precision and Accuracy

Binaries for scale calibration in the Transfer Function (TF) Scan mode were selected from a set of potential FGS calibration targets frequently observed by speckle interferometry with 4-m class telescopes. The plan was to derive, on the basis of well calibrated speckle measures, binary-star orbits that could yield, for any date of *HST*-FGS observation, accurate angular separations of the binary components.

In Table 2 we present, for two calibration binaries, angular separations determined from multiple sets of TF scans with FGS3. These scans, made near the center of the field of view, were reduced with the nominal, pre-launch scale value. Also given in Table 2 are the corresponding values of the angular separations derived from binary orbits based on speckle data.

Table 2: Scale Calibration — Preliminary Results

Binary Name	Date Observed	FGS Filter	Angular Separation (arcsec)	
			FGS3 TF Scans	Speckle Orbit
ADS 10360	93: 104	F5ND	0.121	0.120
		F5ND	0.120	
KUI 83	93: 148	F583W	0.323	0.322
		PUPIL	0.323	

Conclusions

Examination of the angular separation values listed in Table 2 for two calibration binaries leads to the following conclusions:

- Scale calibration observations of close binary stars with FGS3 in the Transfer Function (TF) Scan mode and near the center of the field of view (FOV) have shown that *for purposes of close binary-star astrometry, the present on-orbit scale is the same as the nominal pre-launch scale.*
- The astrometric *precision* for close binary stars observed with FGS 3 in the TF-Scan mode and near the center of the FOV is 1 millisecond of arc.
- The astrometric *accuracy* for close binary stars observed with FGS3 in the TF-Scan mode and near the center of the FOV is 1 millisecond of arc.