Duplicity in HST Guide Stars - FGS Serendipitous Survey Results

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ABSTRACT

Data from the Hubble Space Telescope (HST) Fine Guidance Sensor (FGS) interferometers covering twenty two months of guide-star acquisition operations have been analysed for evidence of of stellar duplicity. The data comprise a survey of observed guide stars, all of which are taken from the HST Guide Star Catalog, ranging in magnitude from 9 to 14. The survey results cover a parameter space for the newly found doubles, for the fainter stars, which are of smaller limiting angular separations than in any previous surveys.

The normal HST engineering telemetry data from 13,979 acquisitions on 4882 stars have been processed. The FGS guidance data can reveal duplicity with separations ranging from approximately 30 mas, for the brighter stars, with small magnitude differences, up to the neighborhood of 500 mas, and in some cases to 1000 mas. The fraction of guide stars indicating duplicity is a function of the statistical criteria used, but is over 5% at a very high level of confidence. It is possible that if some some of the brighter and closer pairs could be identified as nearby, that their orbital motions would be rapid enough to allow mass and distance determination on the time scale of a decade if followed with ground-based interferometric and spectroscopic instruments.

A brief catalog of doubles is given, nearly all of which are of certain duplicity. Information for accessing on-line catalogs of large numbers of stars with lesser, but nevertheless strong, probabilities of duplicity and also for the solutions for duplicity from all acquisitions is provided.

Subject headings: Visual Binaries, Binaries, Interferometry, HST, FGS

1. Introduction

Observations with the Hubble Space Telescope (HST) require locking the Fine Guidance Sensors (FGS) onto the interferometric fringes of guide stars. Normally, for maintaining a highly stable placement of targets in the various science instrument apertures, two guide stars are used, one in each of two FGS units (of three FGS units on board HST). Stars used for guidance are selected from the HST Guide Star Catalog (GSC). The GSC, which is available on CD-ROMs from various sources, has been thoroughly described in three papers (Lasker *et al.*, Russell *et al.*, Jenkner *et al.*,1990).

The stars used for guidance span the entire GSC magnitude range, from approximately 9 to 14th magnitude. Guide stars for each HST pointing are chosen by the HST Science Operations Ground System (SOGS) using a software system called the Guide Star Selection System (GSSS), developed at STScI. The FGS instruments on HST are unique in their ability to quickly detect stellar duplicity at a small fraction of an arcsecond with high precision at the faint end of the GSC magnitude range, since ground-based interferometric techniques are generally limited to brighter stars. By comparison, the Hipparchos results are complete only to a magnitude of 10.5, with a limiting magnitude (sparsely covered) of 12.4 and with much lower resolution.

Prior to HST Cycle 5, acquisition data were normally telemetered to the ground with a sampling rate of $1hz$. This temporal resolution was too coarse to yield information on the shape of the interferometer fringes. Beginning in early 1995 a new engineering telemetry format called “HN” was adopted for normal operations to permit detailed engineering studies of the degrading mechanical behavior of the FGS star-selector servos. The HN format provides FGS servo positions and photomultiplier tube (PMT) counts at $40hz$ which allows the shapes of the star fringes from the interferometers to be analysed, and a serendipitous duplicity survey to be carried out in parallel with the planned research of

HST.

The FGS instruments can also be used to accurately determine the relative positions of stars in the FGS fields-of-view and for double-star studies by high resolution interferometer fringe scanning (Benedict, *et al.*, 1992). In the "TRANS" mode of astrometric observing an FGS repeatedly scans the interferometric fringes of the target star in milliarcsecond or smaller steps and thereby achieves a much higher spatial resolution than is obtained in the normal guide-star acquisition mode. But observations for planned astrometric research require dedicated telescope time and must compete with all other scientific programs for approval. The astrometric information from HST guide-star acquisitions may be obtained at no additional cost of spacecraft time for all HST guide-star observations. The acquisition fringe information is obtained in a single scan with a spatial sampling of 6 mas along each of the two orthogonal interferometric axes. Roughly 7000 guide-star acquisitions per year take place as part of normal operations for all scientific programs.

Of the 13,979 acquisitions spanning 22 months of telescope operation in the present study, the number of unique stars observed was 4,882 or about one-third of the total number of acquisitions. These numbers imply three walkdowns per star, but the repeated acquisitions are not equally distributed. Some scientific programs repeat observations many times on the same target while others involve only a single visit to a target.

The double-star detections from the FGS acquisition data are not biased by the duplicity screening process used in the formation of the GSC. The GSC has excluded stars which appear as double on the Schmidt astrograph plates, but the separation detection limit was a few arc-seconds. The FGS double-star detections are well below that level.

The FGS interferometer fringes formed by the guide stars can reveal duplicity from roughly 30 mas to the neighborhood of 500 mas. Limits vary greatly depending on the star brightness, magnitude of the companion, and other factors. Separations of over one arcsecond are possible in the rare cases of doubles which cause the Fine Guidance Electronics (FGE) to fail to recognize a fringe and thus continue the scan up toward two arcseconds. Magnitude differences from 0 to 2 are typical, and higher values up to, and somewhat over 3 are possible for stars at the bright end of the guide-star magnitude range, and at the larger separations.

The brighter stars in the GSC are preferred for best guiding performance, but the brightest stars available in the small FGS fields-of-view are often at the faint end of the GSC magnitude range. All–sky plots of the guide-star coordinates reveal a rather isotropic distribution of HST pointings. The HST extragalactic research programs select against the galactic plane, leaving no predominance of low galactic latitudes, and perhaps a slight deficit.

The incidence of binaries in the 9-14 magnitude range with separations of a small fraction of an arc second has not been well known in the past. Pre-launch estimates of statistics of guide-stars predicted higher FGS lock-failure rates due to duplicity than that found in operations. The over-estimate was due in large part to overly pessimistic predictions of instrument response to binaries (Hershey and Bély 1994).

The frequency of close binaries among the guide stars is of interest for the planning of guidance of future space telescopes and interferometers, and all binary star statistical information relates in some degree to stellar formation, and evolution. Some of the binaries discovered in this investigation could eventually yield stellar masses with extended study.

2. Acquisition of Guide Stars by the HST FGS

Descriptions of the design and operation of the FGS instruments appear in various sources such as Bradley, *et al.*, 1991, and in STScI documents such as the Fine Guidance

Sensor Instrument Handbook (Holfeltz, 1996).

The FGS operations of interest here are those which generate data while searching for the interferometer fringe after the “spiral search” and “coarse track” processes have located the position of the star to a few tens of milliarcseconds. The motion of the interferometer 5 $\times$ 5 arcsecond instantaneous field-of-view (IFOV) is controlled by integrated units carrying stepper motors, encoders, and deflection optics and which are called “star selectors”. In preparation for the search for the null of the fringe visibility function, the center of the IFOV of the interferometer is offset approximately 0.5 arcseconds from the photocenter of the star in the positive direction of the FGS X and Y coordinates (the “backoff” position). The IFOV is stepped toward the star (the “walkdown”), nominally in steps of a 6 milli-arcseconds in each coordinate, usually at a rate of 25 milliseconds of time per step ($40hz$). At each step the location of the IFOV and the PMT counts are read out to the telemetry stream, providing the data for generation of the fringe visibility functions. There are four PMTs in each FGS, two for each coordinate. When both coordinates have satisfied an algorithm which tests for the presence of a fringe, the FGS is put in the “lock” state in which a $40hz$ servo loop causes the star selectors to follow the null of the fringe in each coordinate as small telescope motions cause the star to shift in the FGS IFOV of view.

The walkdown distance in each coordinate is the angular length scanned on the sky by the interferometers. The geometry of the walkdown scan by the IFOV is shown schematically in Fig. 1. Each interferometer null line is 5 arcseconds wide as it moves through the walkdown distance, generating the hatched parallelograms in Fig. 1. At all times each interferometer can receive photons from the entire IFOV, but the distance of a point source from the null line determines the degree of interference. The walkdown distance in each coordinate is the length of abscisscae plotted in Figs. 2 and 3 (which show eight walkdowns). Due to instrumental alignment differences the walkdown distances vary between the two orthogonal interferometers in each FGS and among the FGS units. Table

1. gives the backoff and walkdown distances in each coordinate for the original three FGS's and for the new FGS installed in place of FGS1 in the February 1997 servicing mission, "FGS1R". The FGE allows only equal backoff distances in the two coordinates.

The relation generally adopted for the generation of a fringe visibility function from the pair of interferometer PMT counts in each axis is of the form $(A - B)/(A + B)$, where A and B are counts in an interferometer PMT pair. The interferometric fringes for unresolved-source visibility functions on each FGS axis, referred to alternatively as "S-Curves" or "Transfer Functions" in the literature, are shown in the references to the FGS instrumental descriptions previously cited.

When the FGS detects a full lobe of the fringe structure, the interferometer moves to the central null, and only half an S-curve is seen in the telemetry. This is the normal or "lock" case of acquisitions. Fig. 2a is representative of walkdowns reaching lock. The duplicity information for a close pair in lock, from half of their blended fringes, is of course far less well determined than from a full scan. If a fainter star lies in the walkdown path, $\gtrsim$ 150 mas from the primary, an S-curve of smaller amplitude but of complete spatial fringe structure will be generated (Fig. 2c,d). Doubles $\lesssim$ 150 mas in separation in one coordinate will show superimposed components (Fig. 2b) and appear as a single, broadened S-curve when separations are near or below 45 mas (Fig. 2a, Fig. 3a).

In less than 1% of the guide stars the FGE fringe detection criterion is not met due to the presence of two stars of nearly equal brightness and separated fringes. Two stars in the interferometer cause the amplitude of each fringe to be half of normal size as may be inferred from the visibility function above. The denominator of the visibility function carries the counts from both stars but only the counts from one star generate the difference $A - B$ for the fringe at each star location. This is the "no lock" case of the acquisition process, and the fringes of both stars are fully scanned, resulting in more accurately determined separations and magnitude differences (Fig. 3). Typically several tries are made if such an acquisition failure occurs, giving multiple full scans. Failure to lock on guide-star fringes is increasingly unlikely to occur in two nearly equally bright stars as separations decrease below 40 mas (Hershey & Bely, 1994), because the positive and negative parts of the S-curves from each star add largely constructively.

3. Extraction and Analysis of the Walkdown Data

The temporal duration of the walkdown to fine lock normally is only several seconds. This is a very small fraction of the target visibility periods which are $\gtrsim$ 52 minutes. Extraction of the $40hz$ astrometric guiding data from the engineering telemetry for the walkdown analysis has been automated by augmenting the Observatory Monitoring System (OMS) software at STScI. OMS normally processes the engineering telemetry for all of the spacecraft subsystems one or two days after it has been generated on HST.

When OMS processes the engineering data, flags for the states of the FGSs are tracked. The "Finelock" flag is set when an FGS begins the walkdown process and the "Finelock Data Valid" flag is set when the FGE autonomously declares lock in both coordinates. By special arrangement for this project, the OMS software writes a file of full $40hz$ resolution data instead of its normal $20hz$ format, from the two star selector encoders and four PMTs for the time interval between the two flags.

The next stage of processing reads the files generated by OMS, and decommutates and appropriately timetags the stream of the 6 parameters of interest (2 encoders positions and 4 PMTs counts for each FGS). The star selector encoder positions are expressed in a curvilinear coordinate system in the HST focal plane, and are converted to Cartesian coordinates internal to each FGS (see above references). The interferometer pairs (whose axes are orthogonal to each other) require the star selectors to be driven at separately varying rates by the FGE to generate a straight line in Cartesian coordinates for the walkdown. The PMT count pairs are converted to a fringe visibility function of the form previously discussed. The sum in the denominator provides a normalization factor only, and so should not carry the noise of individual PMT readouts. It is formed in the analysis as a fixed mean of many readouts.

a. S-curve Fitting Technique

The separate or blended S-curves of a binary are represented as the linear superposition of two single star S-curves with null points and amplitudes to be fitted to the data as represented by Eqs. 1 and 2 for the X and Y instrument coordinates.

$$S(x) = B_{1x} * Sx_{ref}(x - x_{1x}) + B_{2x} * Sx_{ref}(x - x_{2x}) \tag{1}$$

$$S(y) = B_{1y} * Sy_{ref}(y - y_{1y}) + B_{2y} * Sy_{ref}(y - y_{2y}) \tag{2}$$

Here $S(x)$ and $S(y)$ represent the observed visibility data in the respective coordinates and B_1 and B_2 are scaling factors, or S-curve amplitudes, to be found by the fitting process. S_{ref} is a single-star S-curve with its null at the zero point of its coordinate, $S_{ref}(0) = 0$. The ratios of B_1 and B_2 represent the brightness ratio of the two stars. The arguments x_1 and x_2 of the S_{ref} function are the null points of each single-star S-curve to be found by a fitting process.

The single-star reference S-curves differ among the 4 FGSs (3 current and 1 replaced) throughout the full fields-of-view accessible by the star selectors. Each FGS IFOV may be positioned in an arc-shaped field roughly 3.5 by 15 arc minutes on the sky (commonly referred to as a "pickle") and defined by the instrument entrance apertures. The structure of the S-curves differs among the 4 FGSs and for each FGS there is variation in the structure throughout the "pickle". As part of the FGS calibration programs, reference S-curves were obtained in a grid across the 4 FGS fields-of-view with high S/N by the astrometric "TRANS" mode programs on bright stars. These reference data were obtained along with their locations in the 4 FGS instrument fields-of-view from the STScI Hubble Data Archive. Before each walkdown was fitted, a reference S-curve was chosen from the same FGS, closest in distance in the "pickle" to the observed guide star.

Instrumental S-curves are not readily amenable to analytic representation, particularly since they are distorted into complex shapes by the spherical aberration of the HST primary mirror. (There have been no corrective optics installed on HST for the FGSs as for the scientific instruments.) Observed reference S-curves (rather than analytical models) are therefore used in the fitting process which employs numerical techniques.

A differential correction method for fitting was adopted. For each interferometer axis, the method assumes starting values are available which are near the correct values. The starting values are used in the fitting equation to generate a set of residuals, $R(x)$. The residuals are represented as the total derivative with respect to the fitting parameters of Eq. 1. with corrections to the parameters to be determined.

$$R(x) = \sum \frac{\partial S(x)}{\partial p_i} \ \Delta p_i \quad or \quad R(y) = \sum \frac{\partial S(y)}{\partial p_i} \ \Delta p_i \tag{3}$$

Here the p_i are the amplitudes and positions of eqs. 1 and 2. The amplitude derivatives in each coordinate are simply the values of the reference S-curve at the same distances from their nulls, but the derivatives with respect to position require numerical differentiation of the S-curves. Least-squares fits are made for Equations (3) to determine small corrections for each of the parameters. A fraction of the computed corrections are then applied to each parameter value allowing a new set of residuals to be computed. The cycle is repeated until the corrections are a small fraction of their formal errors in the least-squares fit to the current residuals. If oscillation in the parameters occurs, the fraction of the correction used is reduced. A similar fitting method has been successfully used on lunar occultation fringes by Schneider(1985). Sufficient logic is included throughout the initial fitting program to provide stability in the solutions which allows the initial processing of thousands of walkdowns in unattended computer runs.

In principle the number of fitting constants could be reduced in Eqs. 1 and 2 by constraining the ratio of the amplitudes to be the same in both coordinates. Code was developed for combined solutions, but independent X and Y solutions were made for the results presented here. Combined solutions are less convenient for automation with a differential correction technique because assumptions must be made as to the relative position of the fainter and brighter components for starting parameters.

S-curves can be transformed into simple energy profiles, resembling a slit-scan of the component stars, by a Fourier deconvolution method (Hershey, 1992) and then fitted with scaled replicas of the profile of a single reference star. The method was developed for "TRANS mode" observations of complete S-curves which have much finer spatial sampling and much larger S/N than walkdown S-curves, a requirement for Fourier deconvolution. The method is most useful for interpreting "TRANS mode" scans of multiple-stars (Lattanzi,*et al.*, 1994). It can be used to analyse the acquisition walkdown S-curves of higher S/N but introduces an additional processing step.

b. Analysis of Doubles in the "Lock" Case

The walkdown data appear in two basic forms, either arising from a "lock" or "no-lock" walkdown. Undoubtedly many guide stars are double at the 30 mas level and should yield the fits often seen in the results but spurious fits may be generated. As previously noted, the duplicity information on close pairs in the half-Scurve is limited in the lock case. Plots of single star walkdowns reaching lock, closely resemble Fig. 2a. However the solution for

Fig. 2a indicates the half-fringe is broadened as if the star is double. Without independent checks it is not possible to assign a limit for close double detection in lock. Above about 60 mas separation, the blended half S-curves become more clearly distorted by the companion, if not too faint, and provide stronger constraints to the solution for duplicity (Fig. 2b,c,d).

The lock cases have been fit with the differential correction process by first assuming a blended pair with starting values of equal brightnesses and 45 mas separation. From that start, separations from 0 to over 100 mas can be reached by the differential correction process. Usually one star dominates the fit and the other falls to an insignificant brightness. All final fitting constants and their errors are recorded. For the possibility of a wider companion, the remaining half arcsecond of the walkdown outside the locked star fringe is checked for evidence of another S-curve. The most likely position, regardless of how weak, is taken as the starting position. Again if the data do not support a wide companion the amplitude coefficient, B_2, drops to a small value relative to its error but the solution is recorded regardless of the results.

The normal walkdown to lock is not a full survey of the area surrounding the guide star. The nominal width of the interferometer IFOV is 5 arcseconds. The walkdown is at 45° in the first quadrant of FGS coordinates. The scan can be thought of as the scan of a pair of slits arranged in the shape of a plus sign where the bars of the + are 5 arcsec in length, (Fig. 1). The X interferometer covers part of quadrants 1 and 4 in a band 5 arcsec wide, and the Y interferometer covers part of quadrants 1 and 2. In the case of lock, there is no coverage of quadrant 3, as shown in Fig. 1. A companion will be detected in two coordinates only if it lies in quadrant 1. The fraction of doubles detected in two coordinates is predicted to be less than about 18% of all double detections from the ratio of areas in Fig. 1. and a probability density function of separations (based on a weighted mean of the 3 FGSs). The percentage found is 13% from the data for the thirteen thousand walkdowns of this study.

c. Analysis of Doubles in the "No–lock" Case

For the no-lock case, good starting values for the fitting parameters can generally be set and a solution made as in Fig. 3. Autonomously convergent solutions, however, are sometimes difficult to obtain with computed initial parameter values and occasional data anomalies occur, which are not amenable to automated solutions. Starting values are initially generated by computer algorithms but there are options to manually override computed starting values and to rerun the solutions. Some stars yield a lock in one coordinate but a no-lock case in the other. If a guide star fails lock, it is removed from the guide-stars candidate list and thus unfortunately for double-star science is never seen again by the FGS interferometers.

Formal separation errors can be as small as a few milliarcsec. In cases of repeated no-lock walkdowns on the same star, the errors in the solution parameters are determined from the differences of the individual acquisitions rather than from the internal formal errors of the fitting process. Separations have often repeated with standard deviations under 2 mas. Duplicity data from the solutions are provided in Table 2. A full explanation of the tabular entries is given in the accompanying footnotes. For the many stars which have been observed more than once, the standard error of the separation measurements and magnitude differences is given in Table 2.

For either the lock or no-lock cases double star fitting accuracy is primarily a function of star brightnesses. The guide-star range of 9 to 14th magnitude corresponds to a range of a factor of 10 in photon noise. However guide stars in the latter part of the 13th magnitude are acquired with a doubling of the integration time spent at each walkdown step to improve the reliability of the acquisition process and thus the noise range is roughly a factor of 7 from brightest to faintest guide stars.

4. Double Star Statistics

The distributions of separations and magnitude differences (Δm) of the guide stars are shown in Fig. 4. The magnitude distribution of the guide stars chosen for use by HST reflects that of the GSC. This however is not necessarily a perfectly unbiased sample since the brighter stars available in the FGS fields-of-view are preferentially selected.

The histogram of angular separations of the doubles in Fig. 4 is similar to the roughly (1 / separation) distribution functions found in various double-star surveys and catalogs such as the Washington Double Star Catalog (Hogeveen, 1990). Fig. 4 includes single and two-coordinate separations. The separation distribution seen in the guide stars is a convolution of their physical separation distribution with the distance distribution of the guide stars and is limited in range by the capabilities of the FGS's. The larger incidence of binaries at small separations is primarily due to the increase in the number of stars with magnitude and thus statistically, with distance.

The separation distribution in Fig. 4 and the number of doubles detected is a sensitive function of the statistical criteria for duplicity. If the detection threshold for duplicity is set too low, a clear excess of numbers appears near the limit of separation detection for the no–lock cases. The occurrence of such an excess serves as an independent guide on the setting of duplicity criteria for the half S-curve fits. A quantitative measure of the significance level of the fits for duplicity is the ratio of the S-curve amplitudes to their formal errors from the least-squares solutions.

Higher ratios of amplitude coefficients to their errors need to be met in the solutions for close pairs in the lock case, since only a half–fringe is available for fitting. As noted above the half–fringes are susceptible to miss–matches between reference and observed S-curves compounded with all other sources of error (Fig. 2a). The solutions could generate a faint, spurious companion to improve the fit of reference to observed half-Scurves. The criteria for duplicity below 100 mas for the lock case have been set to increase as Δm increases above 1.0 and as separation decreases below 100 mas. Separations at 25 mas in lock with small Δm can meet very high significance criteria. Undoubtedly there are many real doubles at this separation level, although without independent tests, clear limits of validity cannot be set. No lock cases below 35 mas are included in Table 2. A few separations under 35 mas in Table 2 are no-lock cases.

Reducing the significance level required for the solutions for the companions can cause the percentage of doubles to rise to 10% or more with significance levels which are quite strong by statistical standards. There are 269 unique star entries in Table 2 which represents a duplicity detection fraction of 5.5% of the 4882 unique guide stars in this study. With the detection criteria set to yield a conservative 5% duplicity fraction, visual inspection of the S-curves unambiguously confirms the presence of a companion in nearly all cases. Since quadrant 3 is not sampled in the lock cases, the duplicity fraction for the same detection criteria would rise to approximately 7% if corrected for incomplete sampling.

The distribution of Δm in Fig. 4 remains roughly constant up to $\Delta m = 2$ then drops rapidly. Detection of companions is limited by the photon noise in the data which is a function of the magnitudes of the components. For the close cases in lock, the presence of only half an S-curve severely limits the range of Δm. The doubles with $\Delta m > 2$ in Table 2 are generally more widely separated and of smaller systemic magnitudes.

Guide stars are observed across a time interval of a year or more if the scientific target is on a long-term proposal. If the target is visited across intervals spanning several months, then it is likely that the same guide stars are not used because the default roll of the telescope changes. Of the set of guide stars which are repeated across intervals of a year, only a small number show evidence of duplicity in both coordinates. Only a subset of those are likely to be physically close enough to show orbital motion. Detections in two coordinates are needed for a clear detection of orbital motion unless the roll of the telescope remains the same. Thus far these severe requirements leave no star with solutions in both X and Y and a large time interval in the 22 months of coverage. Two cases repeat across a year at different rolls but with one coordinate below the duplicity criterion.

The cases of single coordinate detections carry limited spatial information. As suggested by Fig. 1, a single-coordinate observation indicates presence of a star somewhere along a line 5 arcseconds long, and hence is only a projection of the true separation along the interferometer detection axis. The companion lies somewhere along a line with the position angle given in Table 2, with its closest distance from the primary given by the separation in the Table. Single coordinate detections, however, do yield unambiguous magnitude differences of the stellar components.

5. Follow-up Observations

Many of the pairs discovered by the FGS acquisitions are expected to be middle main-sequence objects and thus meet physical separation requirements which would allow mass determination on the time scale of the order of a decade if followed with ground-based spectroscopy and by ground- or space-based astrometric instruments. For example, a 9th magnitude double, with both components nominal main-sequence G stars of 10th magnitude would be at 100pc. A near maximum separation of 50 mas in a circular, highly-inclined orbit would be due to a semi-major relative orbital axis of 5 AU. The pair would have an orbital period of 7.9 years and a relative radial velocity half-amplitude of 19 km/sec. Distance, luminosity and individual masses can be determined without a parallax from a double–lined spectroscopic binary and the relative astrometric orbit. The FGS acquisition doubles could be screened for the best prospects for mass determination by taking spectra which could distinguish the relatively nearer main-sequence stars from the giants and also by proper motions where available. The separation limits for FGS double-star detection from walkdown data could be clarified by HST TRANS mode astrometry observations, which would help further define a candidate list.

6. Conclusion

The FGS walkdown observations survey stars for duplicity which are generally closer and fainter than any previous surveys. Double star separation and magnitude statistics at any level have relevance to star formation and evolution. The statistics of close double stars in the magnitude range $9 < V < 14$ are of interest in the design of guiding systems for future large space-based telescopes and interferometers, *e.g.* NGST and SIM.

A discovery rate of 5% doubles occurs if the duplicity criteria are set at a level which yields certain duplicity for nearly all of the selected cases and yields about 130 discoveries per year from the guidance data. Undoubtedly many more of the stars are double and lie nearer the limits of detection. Criteria which would yield a 10% duplicity rate produces candidates with a high probability of duplicity. Observations on a test set of candidates with higher spatial resolution and larger S/N would be needed to check this estimate.

A master catalog is kept with all walkdowns and their fitting parameters, Guide Star Catalog numbers, coordinates and all relevant telescope parameters such as roll, filter, FGS servo K-factors etc. The catalog can be searched with any significance criterion for duplicity. Sub-catalogs of double stars for various criteria will be generated. Data will be available at http://starsrus.as.arizona.edu/pub/gsdoubles.html. The catalogs of all solutions for duplicity can be checked for the presence of a specific guide-star number and the significance level found for the solutions for the presence of a double.

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FIGURE LEGENDS

Fig. 1. The geometry of the walkdown scan coverage in reaching lock. Each interferometer null line spans the IFOV. The IFOV in the "walkdown" is moved from the backoff position as shown to the lock position at the intersection of the two dark null lines. The sky coverage by the interferometer scan may be regarded as generated by a diagonal motion of two slits in the shape of a + sign. Only the first quadrant is scanned in both coordinates. The third quadrant is not seen by the interferometers in the case of lock. The coverage is represented in the figure by the hatched parallelograms.

Fig. 2. Examples of walkdowns on double stars reaching lock. Panel a shows a case of lock which is representative of all normal lock cases in appearance. In this case, however, the solution gives evidence of blending with a companion. In panels b, c, and d the primary star is in lock, showing only half of its S-curve. The secondary is sufficently faint that it does not reduce the amplitude of the primary below lock detection.

Fig. 3. Examples of walkdowns on double stars with no-lock. In each panel the interferometer has not met the requirements for lock because the amplitudes of the S-curves are diminished due to the presence of two stars of similar magnitude. In panel d. the full, separate S-curves are generated.

Fig. 4. Histograms of separation and Δm for the selected doubles in Table 2.

The histogram of angular separations of stars is similar to other catalogs, with the general form of a (1 / separation) function.