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FGS Astrometry in Two-Gyro Mode

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Abstract. The Fine Guidance Sensor 1R on board *HST* is used by observers as a science instrument for state of the art relative astrometry and for the high angular resolution of close binary systems. The post observation analysis of FGS science data requires the removal, among other things, of spacecraft jitter and drift that occurred during the observations. Under three-gyro mode this technique had been perfected and implemented as part of the FGS astrometry calibration pipeline. Special tests were conducted in February 2005 to assess FGS astrometric performance in two-gyro mode. No degradation was noted, and no modifications to the calibration pipeline were found to be necessary. FGS science and calibration data acquired since the transition to two-gyro operations in August 2005 confirm the results of the February test. However, in two-gyro mode the scheduling of observations is more restrictive. This especially impacts parallax programs of distant targets at low to moderate declinations since such fields can be observed at only one of the two epochs of maximum parallax factor.

1. Introduction

The *HST* Fine Guidance Sensor 1r (FGS1r) interferometer has been calibrated as an astrometric science instrument. In this capacity it has two modes, Position and Transfer. Position mode is used for wide angle (up to 69 deg^2) relative astrometry whereby the instrument sequentially acquires and tracks the fringes of selected stars residing in its field of view (FOV). In Transfer mode, which can be used to resolve small scale structure, e.g., close binary systems, FGS1r repeatedly scans its 5"x5" instantaneous FOV across a target to obtain data from which the object's interference fringes can be reconstructed (refer to the *FGS Instrument Handbook* for details: Nelan 2005). The post observation processing of both Position and Transfer mode data require the removal of spacecraft jitter and drift that occurred during the course of the observations, which typically span the full 55 minutes of target visibility during an *HST* orbit. The removal of jitter is facilitated by correlating the guide star centroids provided by the guiding FGSs with the centroids from the measurements of the astrometric targets. In Position mode, the measured positions stars which have been observed multiple times over the course of the visit are used to model drift as a second order time dependent polynomial. This model is reverse-applied to the centroids of all the target stars (which removes the affect to the observatory drift). In Transfer mode, drift is removed by cross correlating the observed fringes from the individual scans. Jitter and drift removal is an automated and routine part of FGS science calibration pipeline that was perfected under three-gyro operations.

During the development of the two-gyro mode capability, it was generally expected that spacecraft pointing performance under two-gyro mode would be somewhat degraded relative to three-gyro operations, especially along the axis of the "missing" gyro. However, this did not necessarily imply that the quality of FGS astrometry would be degraded since we expected the jitter and drift corrections of the calibration pipeline to be robust to the new spacecraft pointing characteristics. To verify this, 4 orbits of FGS1r astrometry

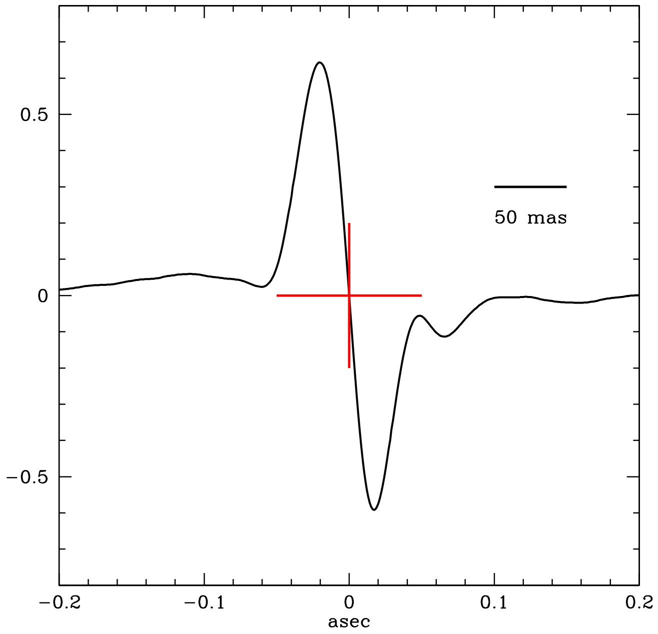

Figure 1: The FGS interference fringe. Vertical direction is fringe amplitude, horizontal direction is angle on the sky. Note the indicated angular scale. During a Position mode observation or while tracking a guide star, the FGS tracks the feature of the fringe at the cross hairs.

were included as part of the February 2005 on-orbit two-gyro mode test (Nelan 2005). Since the transition in late August 2005 to full time two-gryo operations, additional FGS astrometry data from both the GO and calibration programs have become available. The recent data confirm the findings of the February test and shows that the calibration pipeline is indeed well suited for processing two-gyro mode astrometry data. Interestingly, we find that contrary to earlier expectations, there is no significant degradation to the quality of the *HST* pointing control system performance relative to three-gyro operations. We expand upon this in the next section.

2. FGS Astrometry Data in Two-Gyro Mode

In Position mode the FGS tracks the so called "zero-point" crossing of the star's interference fringe (Figure 1). As the position of the star in the FGS detector frame changes, the star selector servos reposition the instrument's optical axis to keep the "cross hair" centered on the fringe. From these adjustments, which occur at 40 Hz (for bright stars), one can track the 2-dimensional (x,y) position of the star in the detector during the course of the observation (the FGS generates fringes in two orthogonal directions).

The guiding FGSs track their respective guide stars in an identical fashion, an important difference being that the guide star centroids are used by the spacecraft pointing control system to fine point and stabilize *HST*. By converting the local (x,y) coordinates of the astrometry target and guide star centroids in the respective FGSs into the vehicle (V2,V3) reference frame, one can compare how well changes in the centroids from the 3 FGSs correlate. A close correlation indicates that each FGS observed changes corresponding to motion of the telescope, while poor correlation indicates that the *noise equivalent angle* of one or more of the centroids is larger than the pointing jitter.

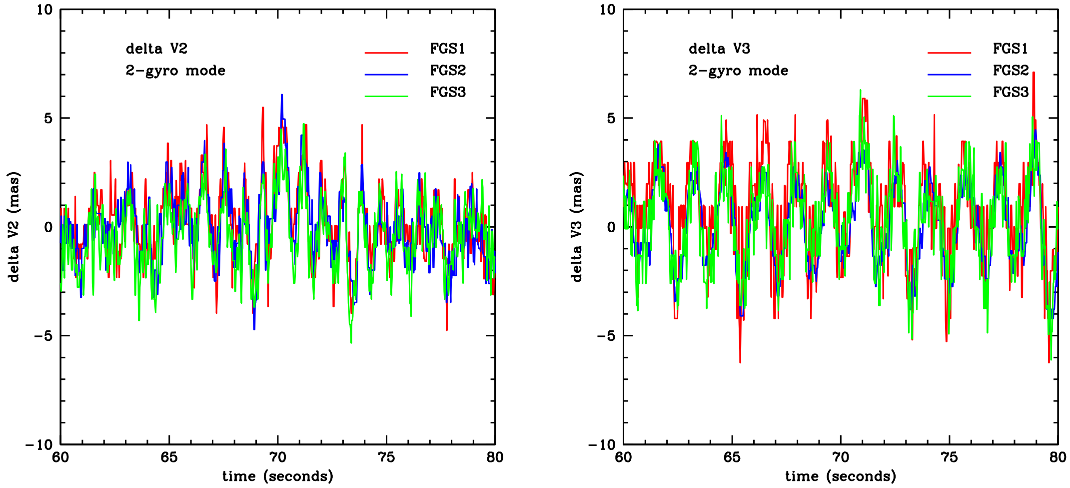

Figure 2: The correlation of V2 (left) and V3 (right) jitter witnessed by the 3 FGSs in a two-gyro mode observation.

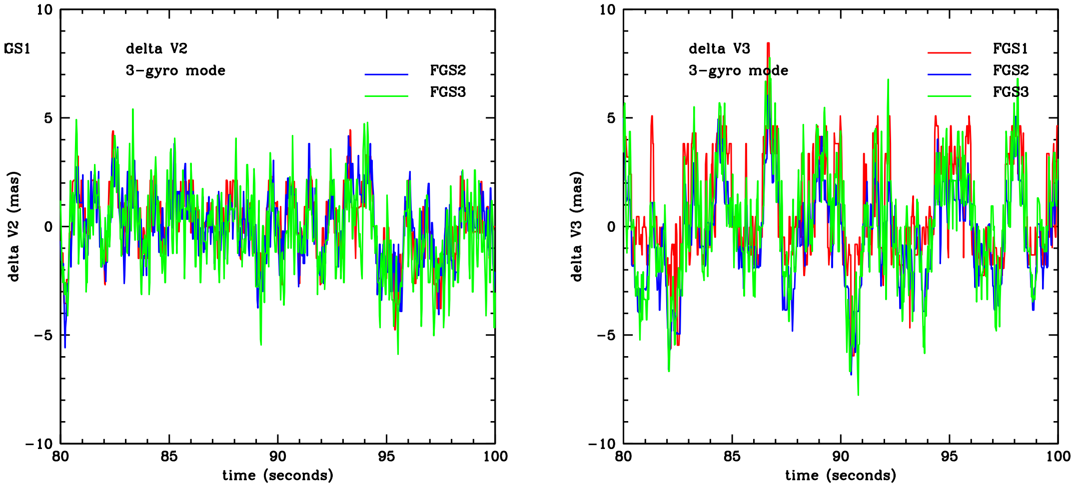

Figure 3: The correlation of V2 (left) and V3 (right) jitter witnessed by the 3 FGSs in a three-gyro mode observation.

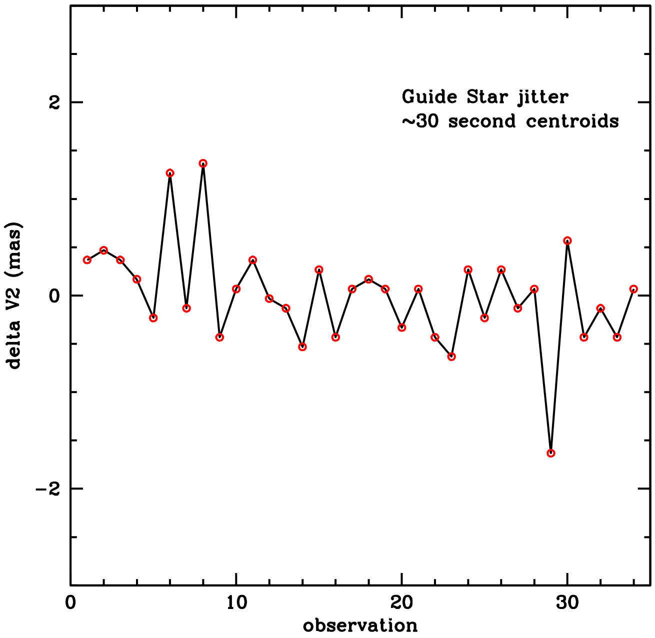

Figure 4: The change in the V2 centroid of the dominant guide star during the course of an astrometry visit in two-gyro operations. The circles mark the temporal midpoints of the individual astrometry exposures. At each point, the guide star centroids are computed over the time of the astrometry exposures. The stability of the guide star centroids in two-gyro mode is essentially that same as in three-gyro mode. This "jitter" is removed by the calibration pipeline.

2.1. Jitter

Figures 2 & 3 show the 40 Hz correlation of an astrometry target star and the two guide star centroids in V2 and V3 for observations under two-gyro and three-gyro operations, respectively. In these two cases all three stars are fairly bright and the data from the three FGSs correlate quiet well. It is note worthy to point out that the amplitude of the jitter is similar in both cases. The apparent periodicity of the jitter is due a vibrational mode of the high gain antennae and is present in both two and three gyro operations. The good correlation across the three FGSs indicates that the guidance data can be used to eliminate jitter in the astrometry data.

However, the calibration pipeline does not use the 40 Hz guidance data for jitter removal. Rather, the pipeline uses the guide star centroids that are computed (via a trimmed mean or a median filter) over the duration of an individual astrometry observation, which is typically 20 to 30 seconds. For illustration, Figure 4 shows the change in the V2 location of a guide star's position in the dominant guider (FGS2 in this case, corrected for differential velocity aberration) over the course of an orbit while FGS1r executed astrometry observations. The small circles mark the mid-points of the astrometry observations. The data plotted here are from two-gyro operations. This is consistent with three-gyro performance.

2.2. Drift

The drift of the *HST* focal plane across the sky during the course of a visit is a familiar phenomenon that is generally attributed to "breathing" of the telescope, i.e., the change in focus due to displacement of the secondary mirror in response to thermal cycling. If

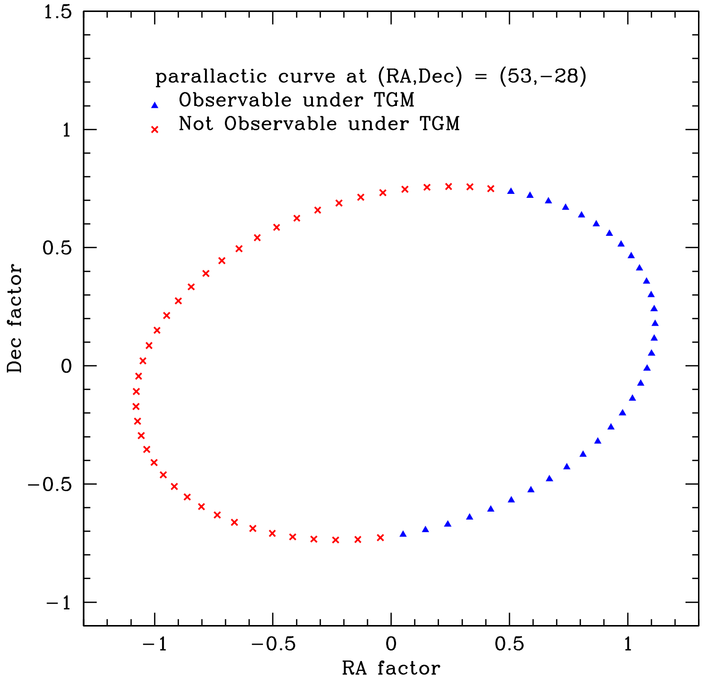

Figure 5: Schedulability of a target field as a function of the fields parallax factor, or day of year. Observation at epochs of "blue" parallax factors, or days, can be scheduled in two-gyro mode, the "red" days cannot. for clarity, every fifth day is plotted. The choice of the HST UDF is for illustration only.

not accounted for, this effect would impress an error of about 5 mas on FGS astrometric measurements. As discussed in the introduction, the effect is easily removed provided several selected stars are observed multiple times over the course the *HST* visit. The signature of this drift is, as expected, unchanged in two-gyro operations compared to three-gyro operations.

2.3. Transfer Mode

As discussed above, under two-gyro operations the spacecraft jitter and drift characteristics are not appreciably different than in three-gyro operations. Therefore, no change in the quality of data acquired by FGS1r in Transfer mode is expected. Indeed, the results of the February test demonstrated this. GO and calibration data obtained since the commencement of two-gyro operations in August 2005 confirm this conclusion.

3. Scheduling

Some astrometric programs may be impacted due to the more stringent scheduling constraints in two-gyro operations. In particular, the fixed head star trackers (FHTS) must not be occulted by the Earth since they are needed to coarse guide the telescope as the guiders acquire their respective guide stars (the FHSTs view the sky in a direction ≈perpendicular to the V1 axis). This eliminates access to one of the two epochs of maximum parallax factor for a given target field, an effect that has greater impact with decreasing declination. For illustration, Figure 5 shows the schedulability of observations in the HST UDF as a function of the field's parallax factors in RA and Declination, which each symbol corresponding to a particular day of year (every fifth day was plotted for readability). For this particular field, the optimal times to observe for a parallax program would be at the extreme ends of the ellipse. However, in two-gyro mode observations can only be scheduled on the "blue" days.

The impact of these scheduling constraints will increase the error of a parallax measurement, but not generally by the amount which is proportional to the reduction in difference of the parallax factors at the epochs of the observations. Other sources of error enter as well, such as residuals of the geometric distortion calibration, and the conversion from relative to absolute parallax. Nonetheless, for targets near the distance limit (d $>\approx$ 400 pc) of accurate FGS parallaxes, the scheduling constraints become important for moderate to low declination fields.

4. Summary

FGS astrometry in two-gyro mode yields data of the same quality as that obtained in three-gyro mode. No modifications to the calibration pipeline or the calibration program are found to be necessary. The new scheduling restrictions can lead to a reduction in the accuracy of parallax measurements for distant objects at moderate to low declinations.

References

Nelan, E., et al. 2004, *Fine Guidance Sensor Instrument Handbook*, version 14.0 (Baltimore: STScI)

Nelan, E. 2005, *FGS Astrometry in the Feb 2005 On-orbit Two-Gyro Mode Test* www.stsci.edu/hst/HST_overview/TwoGyroMode/documents/FGS.pdf