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Thermal Motion of the STIS Optical Bench

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Abstract. Various tests have been done of the STIS using internal wavecals to measure thermal motion of the spectral format on the detectors. In most cases, the spectral format moves less than the specification not to exceed 0.2 pixels per hour. Primary causes of the motion are 1) changes to the thermal design dictated by the warmer Aft Shroud environment and 2) on-orbit power cycling of MAMA electronics to minimize the effects of radiation hits on the MAMA detectors. The rear portion of the STIS optical bench is too warm to be held at a constant temperature by internal heaters. Electronics swing in temperature with an orbital and daily frequency. The thermal drift of the optical formats is not negligible, but is well-behaved in most circumstances. The observer is advised to examine the trade-off between the most accurate wavelengths with best spectral/spatial resolutions versus increased overheads that directly affect the observing times. A long term concern is that the Aft Shroud thermal environment is predicted to heat up as much as one Centigrade degree per year. Progressively more of the bench would move out of thermal control. Thus the external cooler for STIS, being considered for the Third Servicing Mission is of major importance to the long term operation of STIS.

1. Introduction

The STIS was designed, built and tested over a fourteen year period with the goal that it would provide multiple capabilities of spectroscopy, imaging spectroscopy and imaging over the spectral range from 1175A to 10000A. As with all instruments that go into the HST, the STIS was designed to the specifications in the Interface Control Document (ICD). Unfortunately, reality has a way of changing the operating environment when hardware gets close to delivery. STIS has been no exception: In March, 1996, five months before the scheduled delivery of the instrument to NASA, the STIS team was notified that the thermal environment in the Aft Shroud was going to be warmer than specified in the ICD. Moreover, the thermal models predicted, based upon the first six years of HST operations, that the thermal environment would increase as much as one Centigrade degree per year (models incorporating the ACS and COS have not been fully studied at this time). These changes in the thermal environment caused great concern to the STIS development team as the hotter thermal environment and projected warming trend placed the operation of the STIS detectors at great risk. Indeed the thermal environment for the CCD threatened to

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exceed the operational range of the thermal electric cooler (TEC), leading to the potential of thermal runaway. The MAMA temperatures were projected to be much hotter than the original design specifications. As STIS was less than two months from thermal vacuum testing, changes were quickly done to protect the detectors. Heat pipes were added to the MAMA detectors and insulation was removed from the area surrounding the optical bench to provide better heat conductivity to the external panels.

However increased thermal conductivity is a double edged sword. The STIS optical bench became more vulnerable to thermal changes in the Aft Shroud. STIS was placed in a quadrant on the sunward side. Hence the heat load on STIS changes with solar beta angle, and with spacecraft roll. When the side of HST is directly illuminated (beta=90), the side panels of STIS receive significant heat input, but the MAMA heat pipes conduct very effectively to the cold surface of the STIS aft bulkhead. Moreover, if HST is rolled with the Sun impinging more directly on the STIS quadrant, the outer panels of STIS receive even more heat input. The maximum roll is about thirty degrees from the nominal Sun line, and, at beta=90, provides the hottest environment for STIS. The coolest environment for STIS occurs when HST is pointed in the antisun direction. The MAMA heat pipes cannot conduct the detector heat away as effectively, but the outer panels of STIS see a significantly colder environment. In one SMOV proposal (7087), we tested the STIS thermal responses in these two conditions by observing an astronomical source in the continuous viewing zone (CVZ) for five orbits, then slewing to a source located in the anti-sun direction and monitoring until STIS achieved a relatively stable cold environment.

We tested the STIS optical bench thermal stability before launch during the thermal vacuum tests at Ball and in ambient air at Goddard. We could not fully duplicate the on-orbit environment, but we did bracket the thermal extremes that were expected to be encountered in the specified five years of on-orbit operations. But the thermal vacuum tests provide insight on how the STIS will operate in equilibrium. The key issue in the optical bench thermal motion is how the bench responds to transients, both external and internal. The thermal design philosophy has been to minimize the thermal changes and to make sure any changes in the optical bench occurred slowly. During the thermal vacuum tests, limited tests were conducted on the optical bench motion by measuring the displacement of spectra in the hot and cold extremes. After delivery of STIS to Goddard, we were limited to testing in ambient air. We could measure the thermal motion of the STIS optical bench as the internal electronics went from ambient to full operation.

On-orbit testing was done for several situations. In addition to the CVZ/ anti-sun thermal conditioning test, we tested the thermal motion of the STIS optical bench in less ideal, but more realistic, on-orbit conditions. The CVZ spacecraft orientation basically conditioned STIS in a hot environment. Then HST was moved to an anti-sun orientation for thirteen orbits. We allowed the STIS to stabilize for the first eight orbits, monitoring the motion of the CCD mode G230MB, then the NUV MAMA mode E230H was interleaved with the CCD. Typical observations with the STIS will not have the benefit of a thermally-stabilized condition, Indeed the thermal environment for the STIS instrument immediately before any STIS observation is most likely to be significantly different. While the scheduling is done to minimize spacecraft maneuvers, the more crucial issue is fitting the observations into the allowable period on the long term schedule. With the long slit of STIS requiring very precise roll angles, and with the full scale application of parallel observations, changes in roll of the spacecraft are highly likely with most observations. We should then expect greater visit-by-visit changes in thermal environment for STIS than occurred for the first generation of instruments. To get a feeling for these variations, several proposals tested for thermal motion measured during single orbit observations (7085,7086) and for thermal motion during about four orbit observations (7143,7144).

On orbit, we found a further complication in the thermal environment for STIS. Early into the SMOV activity, the MAMA electronics were found to be partially reset by radiation events during the SAA passages. Bench testing of engineering units of the MAMA electronics demonstrated that infrequent partial upset condition could increment the high voltage for the MAMA detectors. If the detector received an overvoltage, survivability of the microchannel plate would be at risk. To protect the detectors, the flight software was changed to cycle the MAMA electronics off during SAA passages. As the MAMA electronics provide a very significant heat input to the rear portion of the STIS optical bench, the MAMA electronics must be powered as much time as possible. Bulkhead six mechanically supports the echelle gratings and various optics, plus the MAMA detectors. Thermal motion of the echelle gratings is likely to be induced by the cycling of the MAMA electronics; indeed we show below that this effect is significant.

2. Measurements

Thermal vacuum testing of spectral format motion was limited to measures in the hot and the cold extremes. As the Mode Select Mechanism (MSM) was moved to sample various formats, measures include error in positioning the MSM that is of the order of +/- 2 pixels. The CCD formats tended to move little (spectral direction +4 to -2 pixels; spatial: +2 to -2 pixels). Each CCD mode appeared to correlate closely with the other CCD modes during a given set of measurements at a specific time and temperature. In units of lores pixels, the MAMA detector formats moved differently: in general the low dispersion formats moved less (+/- 2 pixels both spectral and spatial directions); the high dispersion formats moved more (as much as 10 pixels in both spectral and spatial directions). For comparison the bulkhead six temperature changed by as much as fifteen degrees Centigrade during these tests.

Ambient air testing was limited to measuring format motion due to temperature gradients within the instrument. We note that air convection of heat significantly modified the thermal distribution within the instrument. To keep the instrument dry, nitrogen gas was flowed through the instrument at all times. We adopted a procedure to test thermal motion by leaving the instrument off overnight for at least eight hours. Start up of the instrument was done as rapidly as safely possible to begin measurements of the spectral formats starting at ambient. As the day progressed, wavecals were repeated for a single mode, not moving any internal mechanical device. For the E230H mode, we measured a drift of five pixels over a temperature change of 3.5 centigrade degrees for bulkhead 5; temperatures of bulkheads 5, 6, and 7 were found to track very closely during all tests. The drift was about three pixels in the spectral direction and four pixels in the spatial direction. Thermal motion with time was determined to be less than 0.3 pixels per hour over an eight hour period. The limited testing for E140H in nitrogen gas indicated a similar motion. Other modes had an amplitude two to three times less.

On-orbit testing was done in three modes: single orbit monitoring of selected modes (proposals 7085 and 7086); four orbit monitoring of selected modes (proposals 7143 and 7144); and one test observing the hot condition, the transition from hot to cold condition and the cold condition (proposal 7087). The desired mode of monitoring the thermal drift of the optical bench is to set all internal mechanisms and then take multiple Pt lamp exposures. Dark frames, CCD biases, and spectra of continuum lamps and external sources can be interspersed as long as the slit mechanism, MSM or filters are not moved. A caution must be interjected here that parallel observations are not guaranteed to prevent mechanism movement. When STIS is in parallel mode and the prime instrument moves HST, the planning software apparently homes the MSM. For the single and four orbit proposals, STIS was in parallel to another instrument. Without detailed review of the observation activity, we cannot guarantee that the MSM was moved between wavecals.

The on-orbit hot to cold test (CVZ to anti-sun, proposal 7087) is easiest to understand as the thermal environment for STIS was selected to be initially one of the hottest for visit 1, with an immediate slew to the coldest environment. Between March and August of 1997, the thermal history of STIS on-orbit indicated that bulkheads 1-4 remained very stable, and Bulkheads 5, 6, and 7 have a daily modulation(see `http://www.sesd.stsci.edu/et/stis/stis.html`). Proposal 7087 was executed beginning on 97.197. During the entire visit 1, temperatures of the outer enclosure panels increase upward, with no plateau. The slew from the hot orientation to the cold orientation causes an immediate downward slope. We note that the CCD housing temperature increased by ten degrees as it dumps heat into radiators on the outer panels. The outer panel temperatures flatten out about ten hours later (during the SAA passages with cycling of the MAMA electronics) and then turn up slightly when the MAMA detectors are turned on continously for the last five orbits of the visit.

Because of the SAA avoidance for MAMA electronics, we were able to test only the CCD thermal motion for the entire seventeen orbits. Indeed the first four orbits, spent in the hot orientation, and the last five orbits, spent in a stabilized cold orientation, were not pure thermal motion tests as we moved the MSM between the G230MB (CCD) and the E230H (NUV-MAMA). The MSM does not return to original grating positions to sub-pixel accuracy($\pm$0.2 pixel), but rather to a pixel or two accuracy. The measured positions indicated much higher positioning accuracy, likely due to the MSM going between two very well-defined positions repeatedly.

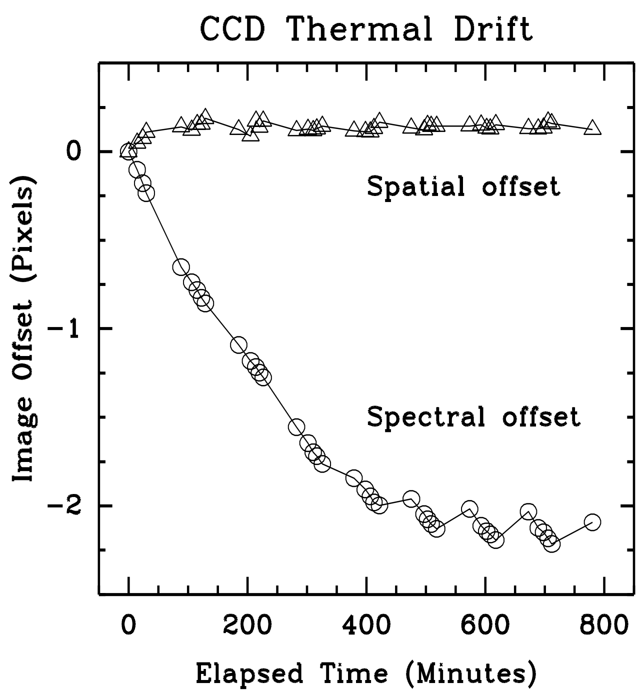

Figure 1. Thermal Motion CCD Mode G230MB for Hot to Cold Transition (Prop 7087)

Moving HST from the hot orientation to the cold orientation yielded a very significant thermal motion for the G230MB format as the enclosure panels cooled down. The CCD format moved at a rate of 0.45 pixels per hour for the first four hours (Figure 1) in the spectral direction (but nearly zero motion in the spatial direction!), then reached a modulated equilibrium by six hours. At that point, the format moves with an amplitude of about 0.5 pixels per orbit. Coincidently the anti-Sun vector pointed through the SAA on the sunward side of the orbits during the first part of visit 2. The CCD thermal motion has a weak, orbital-period modulation consistent with heating on the back of the spacecraft from the sun during the SAA passage and cooling during the non-SAA portion of each orbit when the MAMA low voltage electronics is turned on.

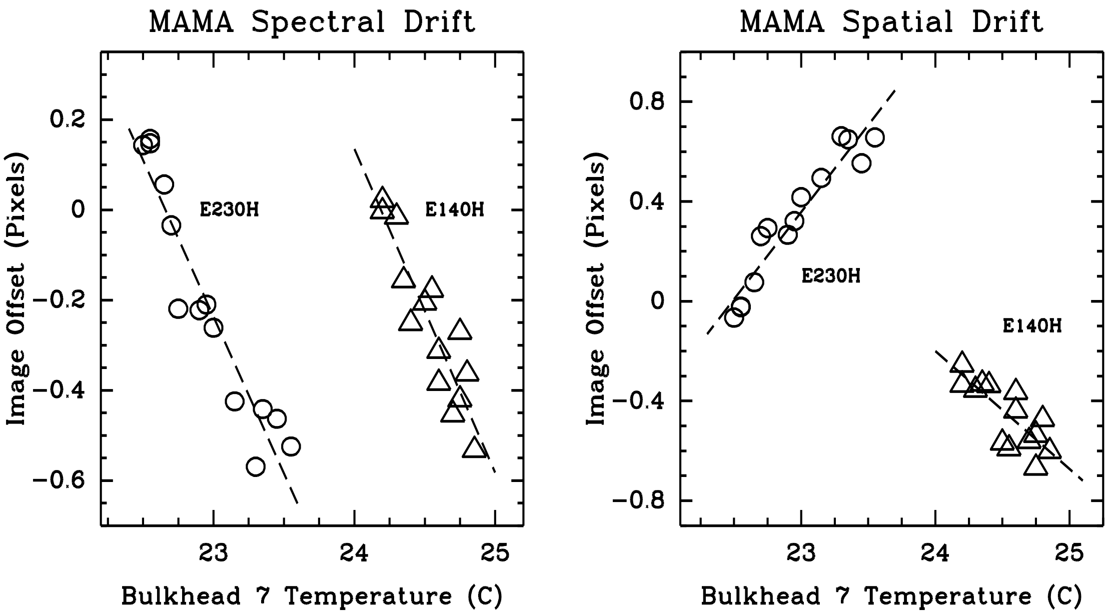

Figure 2. Thermal Motion MAMA Modes E230H and E140H (Prop 7144-5)

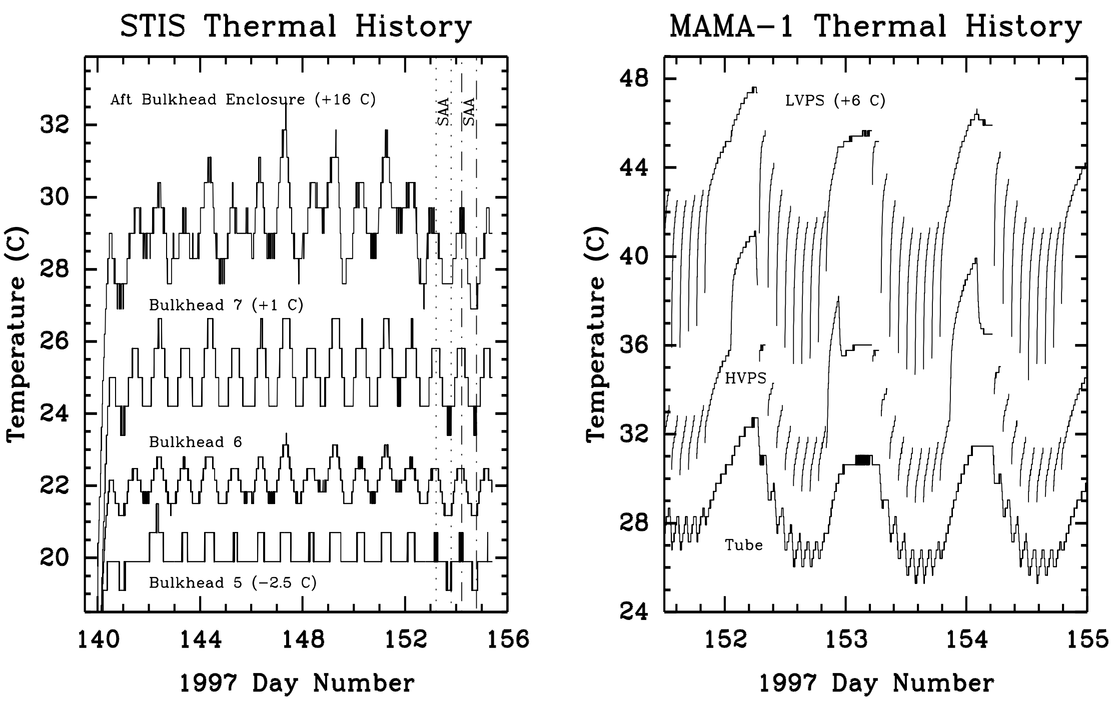

Figure 3. Thermal History of NUV MAMA and Bulkheads

Within each twenty-four hour period, additional thermal cycling influences the optical bench. The temperatures for the low voltage electronics, the high voltage electronics and the tube change as (1 the low voltage electronics are cycled on and off around the SAA passages, (2 the high voltage electronics are cycled on for the period of MAMA usage, and (3 the high voltage is applied to the FUV-MAMA detector (Figure 2). The aft portion of the optical bench is above the set point of the thermal control electronics, so the heaters designed to keep that portion of the bench in balance are of no use. Instead each bulkhead toward the rear has increasing temperature modulation due to these three effects. Proposals 7143 (CCD) and 7144 (MAMA) were designed to measure the influence of cycling the MAMA electronics on and off. Internal wave calibrations were done for four orbits each with STIS in parallel mode.

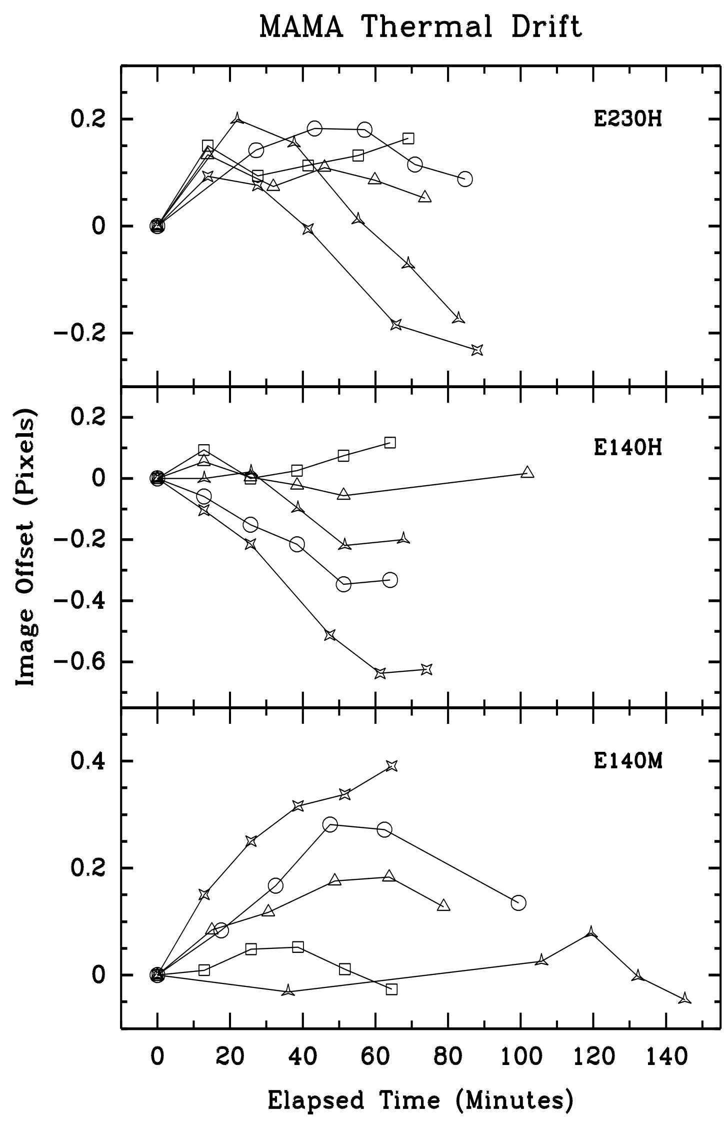

Figure 4. Thermal Drift in Spectral Direction for Echelle Modes (Prop 7086)

Heat input to bulkheads 5-7 warms the deck upon which the echelle and several mirrors are mounted. As the deck heats, the primary change is an "oilcanning" effect where the center of the deck moves axially and the deck warps in a radial tilt. The thermal motions (Figure 3) with temperature measured for modes E230H and E140H are consistent with an oilcanning. The spectral shift is about -0.6 pixels per centigrade degree for both modes, but the spatial shift is about 0.7 pixels per centigrade degree for the E230H and -0.3 pixels per centigrade degree for E140H. For the four orbit tests done under proposal 7144, the thermal motion with respect to time was about 0.3 lores pixels per hour. The CCD motion was significantly less and appears to be predictable.

The normal application of STIS is likely to be a single orbit, or a few orbits per mode. In proposals 7085 and 7086, measures of spectral motion were taken over single orbit periods. Here the CCD motions appear much more predictable with one qualification: our limited data indicates that the zero-point may move around (MSM positioning inaccuracies). The thermal motion collapses to a common curve that is linearly fitted with a slope of 0.3 to 0.45 per centigrade degree. Shifts are 0.2 pixels per hour or less. The echelle modes were less consistent. Thermal motion in the spectral direction seemed to change from visit to visit, even to the extent of change in slope. The motion does not seem to correlate well with the bulkhead 7 or the aft bulkhead temperatures. However a caution must be added here. These observations were done with STIS in parallel mode, and if the primary instrument was moving the spacecraft, then the HOME command would have been issued, leading to a reset of the MSM position. Since the MAMA camera mirror focal length is longer and the MAMA pixel size is smaller than that of the CCD, then the effect is more pronounced for the MAMA measures. In the spectral direction we measure thermal drifts ranging from 0 to 0.6 pixels per hour (Figure 4 and Figure 5)

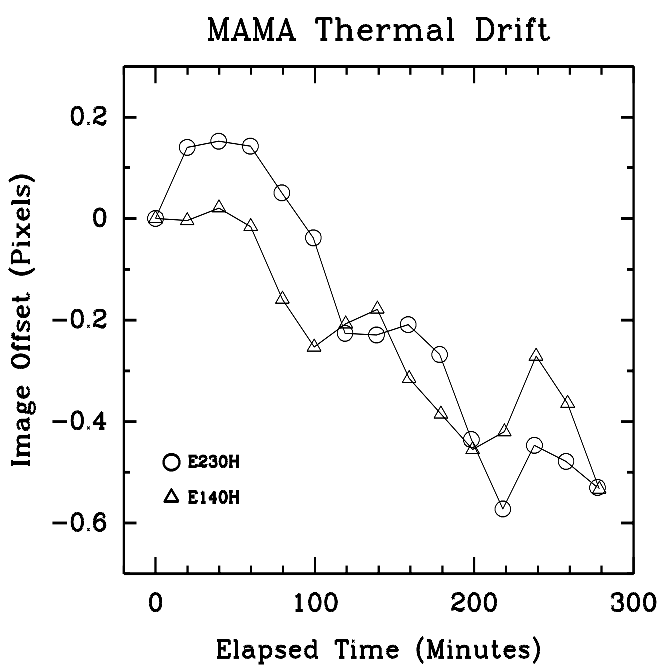

Figure 5. Thermal Drift in Spectral Direction for Echelle Modes: Multiple Orbit Monitoring (Prop 7145)

3. Discussion

From the above data, a measurable thermal motion is found for all STIS modes tested to date. Many tests indicate that typically the thermal motion is about 0.2 pixels or less per hour. Under extreme thermal changes, the MAMA echelle modes can move in the spectral direction as much as 0.6 pixels per hour. Substantial changes in beta and roll angles lead to major changes in solar flux on the STIS quadrant. Most observations are likely to occur with the sun-spacecraft angle at about 90 degrees and as the solar flux changes as the cosine, small beta angle changes from 90 degrees should not affect the thermal condition of STIS. Pointing to the anti-Sun direction however drops the solar flux to zero, and affects the thermal conditioning in a major way. We note that changes in roll angle can induce large thermal change as the average roll angle to STIS is 45 degrees and with changes up to +/- 30 degrees, can provide very significant changes in solar flux.

More frequent wavelength calibrations is an obvious solution, but the observer must carefully examine the tradeoffs between scheduling more wavecals at the expense of observing time as wavecals cannot be buried in earth occultation in the current ground planning software. The impact is much more than just exposure time for wavecals as the overheads of setting up the wavecals, and dumping the buffer memory are significant. A standard of doing at least one wavecal per orbit and bracketing a given mode with wavecals should provide enough information for the observer to establish the reference wavelengths to an accuracy of 0.2 pixels. In the case of the MAMA detectors, if the count rate is less than 30,000 per second, timetag mode is highly recommended. Lindler et al (this volume) have demonstrated that thermal drift and jitter can be corrected for sources with reasonable count rates. Higher count rates with the MAMAs (up to 270,000/sec) must be done in ACCUM mode; if the observer is pushing for the limiting resolutions provided by the hires pixels and the smallest slits, the wavecals should be done more frequently, perhaps as often as once every fifteen to twenty minutes.

References

Lindler, D. J., Gull, T. R., Kraemer, S. B., & Hulbert, S. J. 1997, this volume