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Instrument Science Report TEL 2010-02

HST Focus in SMOV4: Strategy for OTA adjustment & SI Focus

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Dec 10, 2010

Abstract
This report documents in summary the observatory-level effort to produce optimal focus during Servicing Mission Observatory Verification 4 (SMOV4). It describes the extrapolation of monitor data available prior to SMOV4, and the resulting decision to adjust the HST Secondary Mirror +3 μm away from the Primary in concert with the active optical alignment of WFC3 and COS in order to maximize image quality and confocality among the instruments. It also provides the historical HST focus dataset used for such long term focus predictions.

1. Introduction

HST focus has been monitored and adjusted throughout the Observatory's life. The monitoring normally consists of phase retrieval determinations of the amount of defocus present in images taken with one or more Science Instruments (SI).

Since deployment, the HST Optical Telescope Assembly (OTA) has shrunk by ~150 μm ($3x10^{-5}$ of its length). This has resulted in ~25 Secondary Mirror (SM) adjustments away from the Primary Mirror (PM) to maintain the focus to the SIs. On top of this long term trend, operational temperature fluctuations produce focus changes which add "noise" to our estimates of the overall focal length of the OTA, some of which can be modeled (Lallo et al. 2005, DiNino et al. 2008).

This long-term shrinkage is ongoing, and upon entering SMOV4, our trending analysis of ACS phase retrieval data indicated a defocus of –2.5 μm at the SM (1μm @ SM = 6.1nm rms wave front error @ SIs). A negative focus value indicates the SM is too close to the PM. Comparable amounts of defocus (positive or negative) are frequently experienced in normal science operations due to thermal variations, but it was desired to remove any systematic offset during SMOV, in order to pass through Cycle 17 and 18 with the new and existing SIs as close as possible to their best focus.

To accomplish this, STScI produced a plan to offset the best-focus position for COS and WFC3 found during their SMOV4 optical alignment by an amount equivalent to the –2.5 µm estimated amount of defocus at ACS. This would leave the old and new SIs confocal within our errors, but ~ –2.5 µm out of focus. This activity was followed by a ~ 3.0 µm OTA refocus on 20 July 2009, in order to leave the SIs at an estimated ~ +0.5 µm focus, slightly overshooting best focus, with the intention of passing through zero and evolving slightly negative over the Cycle 17/18 period.

For a detailed discussion of subsequent camera focus and confocality estimates, and focus trending over this period see Niemi & Lallo (2010).

2. The Data

The body of HST focus-monitor data spans back to a few months after HST deployment on 24 April 1990. It comprises data from various CCD imaging instruments over the mission life. With some exceptions prior to WFPC2 commissioning in 1994, the data is typically obtained approximately monthly, with multiple exposures taken over some significant fraction of an HST orbit. The targets are normally one or more isolated, bright, non-saturating point sources, observed through filters with central wavelengths between ~0.4 and ~0.8 µm. Proposal numbers for the more recent incarnations of the routine focus monitoring program are CAL/OTA 11877, 11316, 11020, and 10752.

From observations such as these, we perform a parametric phase retrieval analysis to recover presumed optical aberrations. See appendix 1 and Niemi & Lallo (2010). The phase retrieval is usually configured to solve for focus, but is also used to fit coma and astigmatism when appropriate to the nature of a particular study. A phase retrieval analysis is performed on each exposure in the visit, often sampling much of an orbit. This has allowed an accurate characterization of the temperature-driven focus changes during HST orbits, and has facilitated the development of a temperature-based focus model (DiNino et al 2008). Using data obtained from the HST engineering telemetry, the model takes temperatures from a number of sensors throughout HST to predict focus. A purely temperature-based model gives some success in explaining short-term focus variations but does not follow long term trends, most or all of which are not thermally driven nor reversible. This requires the addition of a secular function that is obtained by fitting such trends. For the data and analysis discussed here, when we apply the model, we do not include the long term secular component since this is what we are seeking to determine. When used, the model is only applied to data from 2003 onward since this is the time period over which it was developed and fit to observations.

For the purpose of OTA focus maintenance, we desire independent (uncorrelated) measurements, so the data is processed to replace the multiple values for each visit with the single mean value for that visit. The resulting data file records mean focus values and corresponding time stamps. Over the duration of our monitoring, we have utilized various cameras so the file contains results from WF/PC-1, WFPC2/PC, ACS/HRC, and ACS/WFC, as well as a small number of STIS imaging observations. Since there are small focus offsets (non-confocality) between the SIs, the data in this file has been processed to express results with respect to best ACS/WFC focus. This required adding –1.0 µm to ACS/HRC data, –1.4 µm to WFPC2/PC, and +5.7 µm to STIS image data. WF/PC-1 results were used "as-is" since a reliable estimate does not exist for confocality between WF/PC1 and the other imagers. The large offset for STIS is due to STIS focus being optimized at the slit plane which is not confocal with the image plane, and it is this image focus that is measured by phase retrieval as reported here.

The resulting file currently contains 363 independent measurements spanning from 1990 to March 2009. It is provided in appendix A3. ACS observations (WFC or HRC) are indicated by a "j" as the first character in the filename. WFPC2 data begins with a "u", WF/PC-1 is identified as "pre94", and in some instances (as well as for STIS) the points are named by the proposal and visit number or other descriptive label.

As already described, the HST OTA exhibits a long-term shrinkage, which is periodically corrected by commanding the SM away from the PM. Thus, in order to fit the long term behavior to make predictions used for effective control of the OTA focus, the measured focus values in this file must have accumulated offsets removed in order to reproduce the continuous focus trend rather than observed focus as maintained by periodic OTA refocusing. The history since 1994 of such mirror moves, their amounts and dates can be found at:
http://www.stsci.edu/hst/observatory/focus/mirrormoves.html
A peculiarity in the historical record should be pointed out here; mirror moves prior to 1994 are already captured in our input file. This can be seen in the first 44 rows identified as "pre94" (appendix 3). These values reflect the accumulated defocus up to 1994, rather than the measured values, so do not require piecewise processing to account for mirror moves prior to 1994. This processing of the file is accomplished by simply adding to each measured value the sum of all Secondary Mirror moves that occurred after the date of that observation. This recovers the smooth lifetime behavior whose predictive utility is discussed in the next section.

Finally, we maintain ancillary data files where aberrations such as coma and astigmatism are tracked, along with a number of other characteristics and correlations of interest, but for the purpose of OTA focus maintenance and prediction, the focus aberration is of interest, and the simple file reproduced in appendix 3 comprises the basic input.

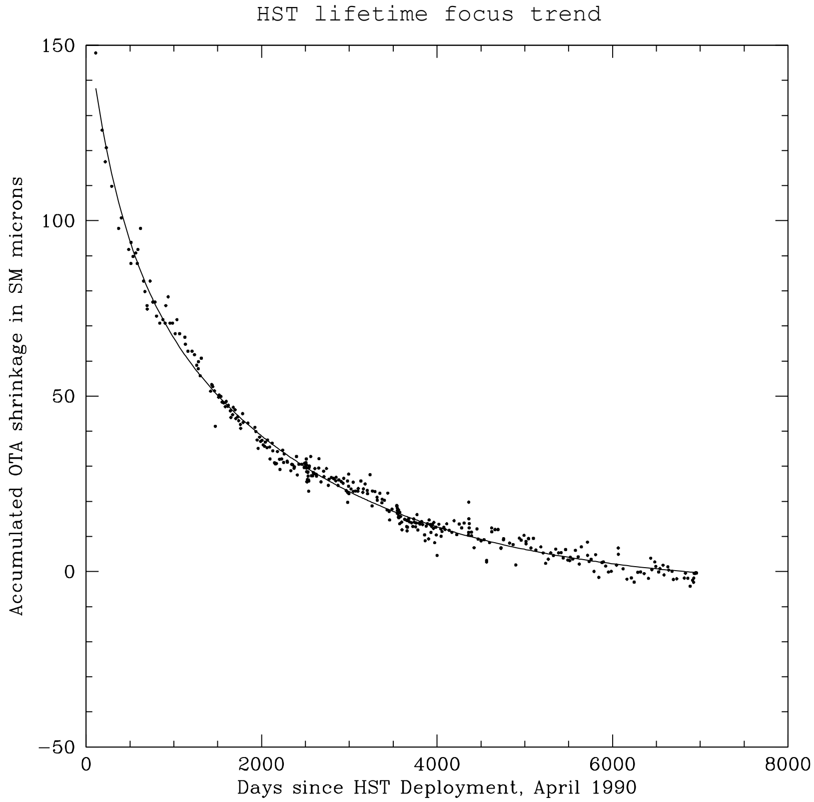
3. SMOV4 Focus Estimate

Plotting the mission-life focus data, after removing the OTA refocusings, produces a trend, with real focus variations creating "noise" about this otherwise monotonic behavior. In fig. 1 below we see this focus data evaluated prior to SM4. The best fitting double exponential,

$$\text{Eqn. 1: } \Delta SM = -5.04 + 56.26e^{-t/364.53} + 106.24e^{-t/2237.2}$$

(where ΔSM is the change in SM position in microns and t is the number of days since 24 April 1990) produced a reasonable fit to the long-term data up to the cessation of HST science in May 2009 in anticipation of SMOV4 (last points plotted). The overall shrinkage of the HST OTA can be seen as ~150 µm. In practice, we have executed OTA refocusings listed in the provided URL to counteract this trend and maintain focus to typically within ~5 µm maximum at the SM.

Figure 1: Accumulated defocus of the OTA over the mission lifetime prior to SM4 (April 1990 - April 2009), and the best fitting double exponential.



Although the lifetime fit is illuminating for understanding long-term behavior, its rms residuals of 2.7 μm (after focus model correction discussed in sect. 2) is too high to accurately base an OTA refocus determination. Systematic long-term displacements above and below the best fitting curve can be seen in figure 1. Because of this, fits to more recent data are often used when determining the overall OTA focus for the purposes of planning an OTA refocusing. This was the case for determining the SMOV4 focus. We examined only the portion of the focus data taken after the December 2002 OTA refocus. The data spans two OTA refocusings indicated in figure 2 by dotted vertical lines. These focus adjustments of +4.16 μm (22 Dec 2004) and +5.34 μm (31 July 2006) were added back into the observed focus values to produce a continuous dataset. This was then best fit with a single exponential,

Eqn. 2: $$\Delta SM = -6.16 + 201.64e^{-t/1754.4}$$

This fit had rms residuals of 1.7 μm and predicted a focus value of –2.5 μm for 1 August 2009 (rough date for the intended OTA refocus). A straight line fit had slightly higher rms residuals of 1.8 μm and predicted –3.4 μm on 1 August. For comparison, the double exponential fit to the lifetime data predicted –1.5 μm with 2.7 μm rms residuals, clearly underestimating the amount of actual defocus seen in monitoring data for the past 1.5 years. An exponential fit performed without model correcting the data increased the rms residuals to 2.0 μm but did not result in a significantly different fit or focus prediction, confirming that the temperature-based focus model was not introducing a systematic offset over the timescale being considered.

It is interesting to note that the constant term in both exponential fits given in equations 1 & 2 imply a total future shrinkage of the HST OTA of only another 5 to 6 μm.

Figure 2: Accumulated defocus of the OTA from 2 December 2002 up to and including SMOV data points (identified with red arrows). Data have been model-corrected. Best fitting exponential predicted a focus of –2.5 microns on 1 August 2009. Best fitting straight line is dashed and included for reference.

The best estimate of –2.5 μm of defocus at ACS implied an equivalent amount of defocus at the STIS slit plane, since STIS and ACS were both originally focused to be confocal with WFPC2 and thus should remain confocal within the errors to each other. Early SMOV calibration results included a phase retrieval measurement of a STIS CCD OII image, which indicated that, like ACS, the resurrected SI had not seen a noticeable focus change since the last time it was operational. After correcting by the 5.7 μm to express this measurement at the STIS slit focus (see sect. 2), this point was seen to be slightly more positive than expected, though it was not "out of family" with other outliers seen throughout our monitoring history. Additionally, STIS CCD phase retrieval results have carried higher errors than seen with the more frequently utilized imagers due to coarser calibrations of the algorithms consistent with their less frequent application to that SI, along with uncertainty associated with the focus offset between the imaging and spectral modes. The STIS image-plane focus check made during SMOV was thus performed more as a gross indicator of any possibly new large focus offset within the instrument, rather than as a sensitive measurement of OTA focus state.

4. SMOV4 Focus Adjustments

The SMOV focusing plan that emerged from this estimate of –2.5 µm at the SM was as follows: offset WFC3 & COS foci during SI SMOV fine alignment by the equivalent of –2.5 µm to achieve confocality with ACS/WFC, then follow up with a +3.0 µm OTA refocus (prior to WFC3 PSF specification tests and Early Release Science). This OTA adjustment would then leave the SIs at ~ +0.5 µm focus, intentionally slightly overshooting best focus. Predictions using the best fitting exponential (eqn. 2) put best focus for the SIs near mid cycle 17 (summer 2010). Focus monitoring throughout cycle 17 would then establish the success to which confocality and best focus was achieved.

During SMOV4, between 7–9 July 2009, WFC3 UVIS & IR Fine Optical Alignment proposals 11434 & 11435, and COS NUV Optical alignment 11469 executed. These programs featured near-real-time "ops requests" to actively command the instruments' optics into their final positions for best overall image quality based upon analysis performed on images obtained earlier in the same programs. The final uploaded positions for the SI optics were biased at that time by the equivalent of –2.5 µm focus. The actual commanded values associated with the optical alignment of these instruments are described in Hartig (2009a, 2009b, 2010).

On 20 July 2009, a Secondary Mirror move of +3.0 µm away from the PM was executed by engineers at GSFC. The actual commanded amount of this move was +2.97 µm due to SM actuator quantization. This OTA refocus was smaller than most of the routine shrinkage-compensating adjustments that had been applied in the past. However, WFC3's imaging performance is believed to require tighter focus control than other HST imaging instruments, and the initial desire to stay within 2 µm of defocus was adopted. After experience with WFC3 images in cycle 17 there is some evidence that a tighter focus control (e.g. +/–1 µm) may realize measurable improvement. This will be investigated further in cycle 18.

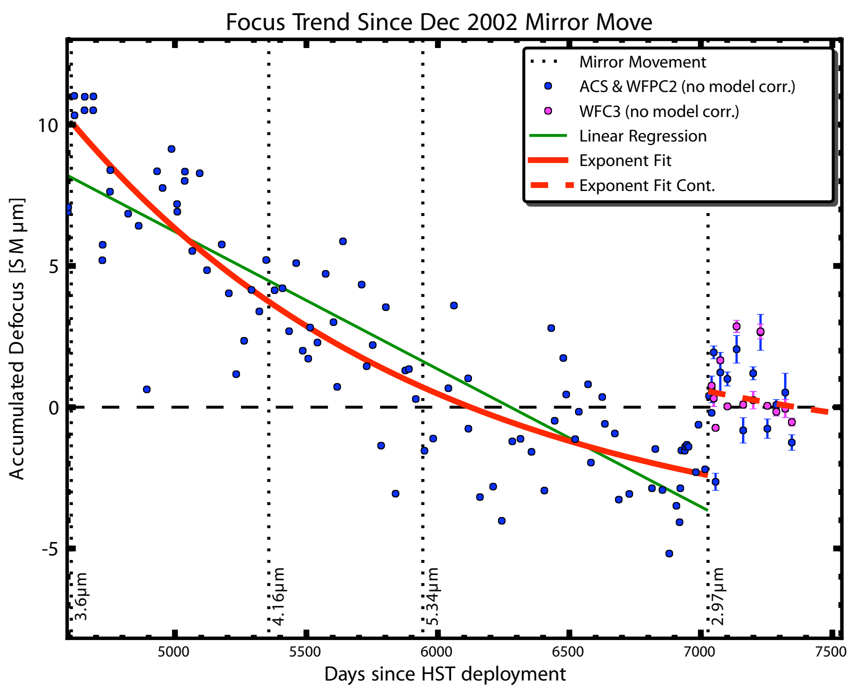
The timeline and decision tree specific to SMOV4 focus that was developed to prescribe contingency plans for focusing new or existing SIs is reproduced in appendix A2. In fact, other than the described biasing of the new-SIs followed by the OTA adjustment to optimize focus and confocality, no other active focusing activities were performed during (and since) SMOV4. The OTA and the repaired SIs (STIS and ACS) were found to not have experienced any gross changes across the Servicing Mission boundary, or while inactive prior to repair.

5. Post-SMOV4 Focus Monitoring

Since the SMOV focusing activities, proposal CAL/OTA 11877 has been used as the primary monitor of overall focus. The data are analyzed using phase retrieval analysis of images taken with WFC3/UVIS and ACS/WFC, either in parallel or within the same orbit. The phase retrieval code requires SI-specific information in order to accurately characterize apparent optical aberrations like focus, and considerable investment was made during cycle 17 to adapt and calibrate the algorithms for WFC3. Niemi et al. (2010) give a thorough review of this.

Figure 3 plots focus monitoring data obtained since the SMOV4 period, illustrating the success of our SMOV4 focus initiative at restoring overall focus and producing practically confocal main imagers. A full treatment of findings & results since the SMOV4 focusing initiative can be found in Niemi & Lallo (2010).

Figure 3: Defocus of the OTA from 2 December 2002 up to June 2010, including data taken since the 2009 Secondary Mirror Move in late SMOV. Evident is the resulting overall state of WFC3/UVIS and ACS/WFC near best focus through cycle 17 (mirror moves prior to the last are indicated but have been removed to show a continuous trend).



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Appendix

A1. Phase Retrieval

Routine optical monitoring of HST is performed using IDL code to perform parametric (model-fitting) phase retrieval of a nearly in-focus PSF. The technique iteratively generates model PSFs and compares them with the observed data (Krist & Burrows 1995). The wavefront is characterized by the series of Mahajan Zernike polynomials modified for the 0.33 obscuration applicable to HST. They are listed below and discussed in greater detail in the OTA handbook (Burrows 1990). Current application and adaptation for WFC3 is described by Niemi et al. (2010).

The phase retrieval process produces an estimated wavefront described by the series:

$$W(r, \theta) = \sum_n c_n \alpha_n Z_n \qquad (1)$$

where Z_n are the Zernike polynomials, α_n are the normalization factors sometimes seen included as part of the Zernike polynomial, and c_n are the solved-for coefficients representing wavefront error in microns. For $n = 4$ to 8, $\alpha_n Z_n$ are given below:

$$\alpha_4 Z_4 = 3.89\,(r^2 - 0.55445)$$
$$\alpha_5 Z_5 = 2.31\, r^2 \cos 2\theta$$
$$\alpha_6 Z_6 = 2.31\, r^2 \sin 2\theta$$
$$\alpha_7 Z_7 = 8.33\,(r^3 - 0.673796r) \cos\theta$$
$$\alpha_8 Z_8 = 8.33\,(r^3 - 0.673796r) \sin\theta$$

In the case of focus ($n = 4$) the c_4 coefficient can be expressed as:

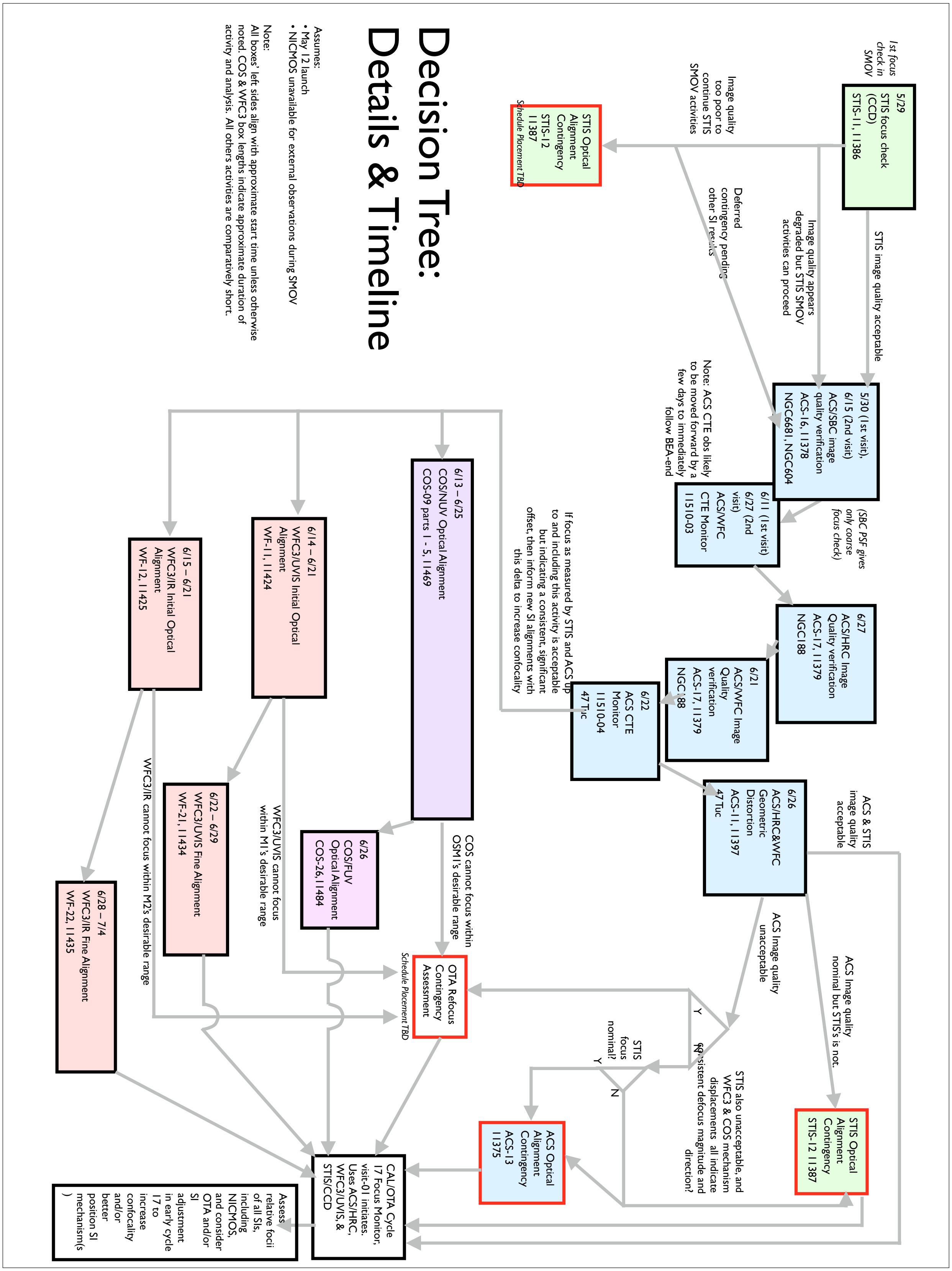
$$c_4 = \frac{1 + m^2}{\alpha_4 8 F^2} \Delta_{SM} \qquad (2)$$

where $F = 24$ = HST focal ratio, $\alpha_4 = 3.89$, m = magnification = $F/f_{primary} = 24/2.3 = 10.43$.

Thus $c_4 = 0.0061 \bullet \Delta_{SM}$

Total rms wavefront error is $(\Sigma c_n^2)^{1/2}$

A2. SMOV4 Focus Decision Tree



A3. HST Focus History Data File

Measured defocus, expressed with respect to best ACS/WFC focus (see section 2). No focus model correction.

ObsName,	Date,	Modified JD,	Microns of Secondary Mirror despace
pre94	pre94	48110	-1.00
pre94	pre94	48183	-23.00
pre94	pre94	48219	-32.00
pre94	pre94	48231	-28.00
pre94	pre94	48292	-39.00
pre94	pre94	48371	-51.00
pre94	pre94	48402	-48.00
pre94	pre94	48486	-57.00
pre94	pre94	48511	-61.00
pre94	pre94	48513	-55.00
pre94	pre94	48536	-59.00
pre94	pre94	48566	-58.00
pre94	pre94	48584	-61.00
pre94	pre94	48591	-57.00
pre94	pre94	48621	-51.00
pre94	pre94	48656	-66.00
pre94	pre94	48671	-69.00
pre94	pre94	48695	-73.00
pre94	pre94	48698	-74.00
pre94	pre94	48730	-66.00
pre94	pre94	48761	-72.00
pre94	pre94	48762	-72.00
pre94	pre94	48786	-72.00
pre94	pre94	48803	-76.00
pre94	pre94	48840	-78.00
pre94	pre94	48876	-77.00
pre94	pre94	48901	-78.00
pre94	pre94	48909	-73.00
pre94	pre94	48936	-70.50
pre94	pre94	48956	-78.00
pre94	pre94	48986	-78.00
pre94	pre94	49016	-81.00
pre94	pre94	49036	-77.00
pre94	pre94	49066	-81.00
pre94	pre94	49126	-82.00
pre94	pre94	49132	-84.00
pre94	pre94	49161	-86.00
pre94	pre94	49208	-86.00
pre94	pre94	49236	-87.00
pre94	pre94	49261	-90.00
pre94	pre94	49279	-91.00
pre94	pre94	49281	-89.00
pre94	pre94	49301	-93.00
pre94	pre94	49314	-88.00
u2a70305t	8/03/94	49419	-2.40
u2a70605t	20/03/94	49431	-0.50
u2a70905t	25/03/94	49436	-0.70
u2a70c05p	1/04/94	49443	-1.10
u2a70i05t	21/04/94	49463	-2.30
u2a70l05t	1/05/94	49473	-12.40
u2a70o05t	8/06/94	49511	-4.10
u2a70r05t	14/06/94	49517	-3.50
u2a70u05t	4/07/94	49537	1.10
u2a70x05t	16/07/94	49549	-0.50
u2a71005p	25/07/94	49558	-0.50

u2a71305t	4/08/94	49568	-0.70
u2a71605t	23/08/94	49587	-1.80
u2a71905t	2/09/94	49597	-0.30
u2a71c05t	21/09/94	49616	-1.70
u2a71f05t	26/09/94	49621	-1.40
u2a71i05t	20/10/94	49645	-3.00
u2a71l05t	25/10/94	49650	-4.90
u2a71o05t	14/11/94	49670	-4.10
u2a71r05t	21/11/94	49677	-2.00
u2a71u05t	12/12/94	49698	-2.70
u2a71x05t	20/12/94	49706	-5.20
u2a72605t	11/01/95	49728	-4.70
u2a72905t	21/01/95	49738	-0.80
u2a72c05t	11/02/95	49759	-1.90
u2a72f05t	13/02/95	49761	-3.00
u2n10203p	7/03/95	49783	1.20
u2n10403t	13/03/95	49789	-1.30
u2o00501t	7/05/95	49844	-1.50
u2s61101t	27/07/95	49925	-2.70
u2s61201t	6/08/95	49935	-3.90
u2s61301t	21/08/95	49950	-6.30
u2s61401t	31/08/95	49960	-2.20
u2s61501t	18/09/95	49978	1.00
u2s61601t	28/09/95	49988	-0.20
u2s61701t	16/10/95	50006	0.10
u2s61801t	29/10/95	50019	-1.20
u2s62101t	13/11/95	50034	-1.60
u2s62201t	22/11/95	50043	-0.40
u2s62301t	12/12/95	50063	-2.00
u2s62401t	18/12/95	50069	0.20
u2s62501t	10/01/96	50092	-1.80
u2s62601t	15/01/96	50097	-5.20
u2s62701t	8/02/96	50121	-0.70
u2s62801t	15/02/96	50128	-2.90
u2s63101t	6/03/96	50148	-6.30
u2s63201t	17/03/96	50159	-0.60
u2s63301t	28/03/96	50170	-0.50
u2s63401t	7/04/96	50180	2.90
u2s63501t	2/05/96	50205	0.70
u2s63601t	7/05/96	50210	-2.20
u2s63701t	27/05/96	50230	0.80
u2s63801t	6/06/96	50240	3.30
u2s63901t	17/06/96	50251	-0.20
u2s64001t	24/06/96	50258	2.20
u3dy0103t	27/07/96	50291	0.17
u3dy0203t	30/07/96	50294	-0.13
u3dy0403t	8/09/96	50334	-2.57
u3dy0503t	17/09/96	50343	-0.77
u3dy0603t	29/09/96	50355	-0.87
u3dy0702t	15/10/96	50371	-1.85
u3dy0802t	19/10/96	50375	-1.45
u3dy0904t	11/11/96	50398	6.50
u3dy1004t	21/11/96	50408	1.23
u3dy1102t	9/12/96	50426	4.30
u3dy1403t	9/01/97	50457	4.27
u3dy1502t	5/02/97	50484	3.35
u3dy1602t	9/02/97	50488	4.55
u3sr0102r	23/02/97	50502	3.90
u3sr0202r	25/02/97	50504	3.45
u3sa1107r	27/02/97	50506	3.92
u3sa1308r	28/02/97	50507	4.31
u3sr2602r	3/03/97	50510	4.13
u3t9810hr	4/03/97	50511	4.00

u3sg0401r	5/03/97	50512	4.10
7021_15	6/03/97	50513	2.34
u3sr3002r	9/03/97	50516	-0.70
u3sr3202r	13/03/97	50520	-0.75
u3sr3402r	16/03/97	50523	-0.05
u3sr3602r	20/03/97	50527	-0.45
u3sr3802r	21/03/97	50528	-0.30
u3sr3902r	24/03/97	50531	-1.50
u3sr4002r	27/03/97	50534	-2.60
u3sr4102r	30/03/97	50537	-5.80
u3dy1901r	31/03/97	50538	-2.90
u3sr4302r	4/04/97	50542	0.95
u3dy2001r	5/04/97	50543	1.40
u3dy2103m	23/04/97	50561	4.10
u3dy2203m	2/05/97	50570	-1.40
u3dy2301m	14/05/97	50582	-1.40
u3dy2401m	22/05/97	50590	-0.50
u3dy250dm	6/06/97	50605	-0.82
u3dy260dm	8/06/97	50607	0.64
u3dy2701m	24/06/97	50623	-1.00
u3dy2801m	28/06/97	50627	-1.50
u42w0103m	22/07/97	50651	0.80
u42w0203m	25/07/97	50654	3.47
u42w0402m	18/08/97	50678	-3.15
u42w0503r	17/09/97	50708	-0.10
u42w0603r	21/09/97	50712	-1.63
u42w0803r	18/10/97	50739	0.67
u42w0903r	10/11/97	50762	-4.13
u42w100dr	17/11/97	50769	-2.38
u42w1203r	14/12/97	50796	-1.87
u42w1303r	5/01/98	50818	-2.13
u42w1603r	6/02/98	50850	0.57
u42w1703r	27/02/98	50871	-1.73
u42w1803r	8/03/98	50880	-0.20
u42w2002r	5/04/98	50908	-0.65
u42w2102r	26/04/98	50929	-1.15
u42w2202r	3/05/98	50936	0.25
u42w2403r	31/05/98	50964	-3.23
u42w5604r	15/06/98	50979	16.10
u42w5801r	17/06/98	50981	12.30
u42w5804r	18/06/98	50982	10.00
u42w5503r	28/06/98	50992	14.60
u4ah030gr	1/07/98	50995	-2.70
u42w2803r	26/07/98	51020	-1.37
u42w2903r	20/08/98	51045	0.57
u42w3002r	22/08/98	51047	-2.05
u42w3203r	16/09/98	51072	-1.97
u42w330dr	13/10/98	51099	-2.00
u42w3403r	17/10/98	51103	-1.23
u42w3602r	15/11/98	51132	0.90
u42w3703r	7/12/98	51154	-2.33
u42w3803r	13/12/98	51160	-1.35
u42w4003r	2/01/99	51180	0.07
u42w4103r	27/01/99	51205	-1.80
u42w4203r	29/01/99	51207	-2.70
u42w4401r	27/02/99	51236	2.70
u42w4503r	22/03/99	51259	-6.20
u42w4602r	26/03/99	51263	-1.95
u42w4803r	25/04/99	51293	-2.10
u5if1107r	18/05/99	51316	-3.72
u5if1807r	20/05/99	51318	-4.56
u5if2809r	20/06/99	51349	-2.60
u5if3107r	12/07/99	51371	-5.30

u5if3807r	15/07/99	51374	-4.30
u5if4809r	11/08/99	51401	-4.60
u5if5808r	9/09/99	51430	-7.35
u5j70502r	17/09/99	51438	0.45
u5if6107r	4/10/99	51455	-4.80
u5if6807r	9/10/99	51460	-7.20
u5if7808r	4/11/99	51486	-4.10
u617e50gr	28/12/99	51540	-3.54
u617270gr	30/12/99	51541	-2.93
u617290gr	30/12/99	51542	-3.27
u60f3108r	3/01/00	51546	-5.29
u60f3208r	4/01/00	51547	-4.51
u60f3308r	5/01/00	51548	-3.89
u6175104r	16/01/00	51559	-2.20
u60n1208r	18/01/00	51561	-0.87
u60n1408r	20/01/00	51563	-2.35
u6176105r	30/01/00	51573	-4.10
u6176805r	31/01/00	51574	-0.83
u60f6108r	10/02/00	51584	-2.02
u5ls4109r	22/02/00	51596	-3.60
u5ls4809r	27/02/00	51601	-5.80
u5ls5809r	27/03/00	51630	-2.80
u5ls6106r	17/04/00	51651	-3.03
u5ls6807r	19/04/00	51653	-4.88
u66k010fr	25/04/00	51659	-6.11
u66k020fr	28/04/00	51662	-3.55
u5ls7109r	15/05/00	51679	-2.60
u5ls7809r	21/05/00	51685	-3.50
u5ls8808r	14/06/00	51709	-3.80
u68w010gr	30/06/00	51725	-1.26
u5ls9109r	10/07/00	51735	0.90
u5ls9809r	15/07/00	51740	0.00
u68w020gr	30/07/00	51755	-1.34
u68x110cr	7/08/00	51763	-0.25
u68x180cr	15/08/00	51771	2.12
u68w030er	26/08/00	51782	-2.25
u68x280br	10/09/00	51797	-0.30
u68w040er	19/09/00	51806	-0.56
u68x580cr	7/10/00	51824	0.15
u68w050er	19/10/00	51836	-0.70
u6b7080cr	10/11/00	51858	-3.65
u68w060er	16/11/00	51864	-5.33
u693580cr	29/11/00	51877	-1.15
u68w0707r	12/12/00	51890	0.50
u68w070er	13/12/00	51891	-1.39
u6936107r	25/12/00	51903	-4.80
u693680cr	31/12/00	51909	0.60
u68w080gr	13/01/01	51922	-0.70
u693710cr	22/01/01	51931	-2.95
u693780cr	28/01/01	51937	-1.20
u68w090gr	10/02/01	51950	-0.49
u6938107r	19/02/01	51959	-1.80
u693880br	24/02/01	51964	-0.10
u68w100gr	5/03/01	51973	-5.88
u69q110cr	19/03/01	51987	-1.45
u69q180cr	24/03/01	51992	-3.67
u68w110gr	2/04/01	52001	-9.51
u69q280br	22/04/01	52021	-0.62
u69q310cr	14/05/01	52043	-1.95
u69q380cr	17/05/01	52046	-4.05
u68w130gr	28/05/01	52057	-2.69
u69q480cr	17/06/01	52077	-1.50
u68w140gr	1/07/01	52091	-2.12

u6hk010gr	21/07/01	52111	-0.49
u6hk020gm	18/08/01	52139	-2.35
u6hk030em	16/09/01	52168	-2.92
u6hk040em	12/10/01	52195	0.39
u6hk050em	11/11/01	52224	-3.57
u6hk060cm	9/12/01	52253	-0.55
u6hk070gr	6/01/02	52280	-1.66
u6hk080em	3/02/02	52308	-0.08
u6hk080gm	3/02/02	52309	-1.70
u8cz2108r	24/03/02	52357	-4.50
u8cz2508m	24/03/02	52358	-2.96
u8cz2708r	27/03/02	52360	-2.93
u8cx0107m	29/03/02	52362	3.46
u8cx010cm	29/03/02	52363	-2.76
u8cx020cm	3/04/02	52367	-1.55
u8cx030cm	29/04/02	52393	-3.60
u6hk120fm	28/05/02	52422	-7.31
u6hk130gm	30/06/02	52455	-1.95
u8hr0103m	12/07/02	52468	-4.83
u8hr020cm	16/08/02	52502	-5.59
j8hr03vyq	18/09/02	52535	-5.66
u8hr030cm	18/09/02	52536	-4.55
u8hr040cm	18/10/02	52565	-11.49
j8hr05xuq	20/11/02	52598	-6.19
u8hr050cm	20/11/02	52599	-6.02
j8hr06n2q	14/12/02	52622	1.52
u8hr060cm	14/12/02	52623	0.83
j8hr07u2q	22/01/03	52661	1.01
u8hr070cm	22/01/03	52662	1.49
j8hr08hfq	24/02/03	52694	1.01
u8hr080cm	24/02/03	52695	1.50
j8hr09d9q	31/03/03	52729	-4.30
u8hr090cm	31/03/03	52730	-3.75
j8hr10r5q	29/04/03	52758	-1.87
u8hr100cm	29/04/03	52759	-1.11
j8hr12dfq	07/07/03	52827	-2.65
u8hr130cm	16/08/03	52867	-3.08
u8hr140cm	16/09/03	52898	-8.87
u8tq010cm	25/10/03	52937	-1.15
u8tq020cm	15/11/03	52958	-1.74
u8tq030cm	19/12/03	52992	-0.36
j8tq04v9q	10/01/04	53013	-2.31
u8tq040cm	10/01/04	53014	-2.58
j8tq05j5q	08/02/04	53042	-1.49
u8tq050cm	8/02/04	53043	-1.16
u8tq060cm	7/03/04	53071	-3.97
u8tq070cm	4/04/04	53099	-1.22
j8tq08raq	02/05/04	53127	-4.65
j8tq10c1q	27/06/04	53183	-3.74
j8tq11f6q	24/07/04	53210	-5.47
u8tq120cm	21/08/04	53238	-8.33
u8tq130cm	20/09/04	53268	-7.15
u94g010cm	18/10/04	53296	-5.35
u94g020cm	17/11/04	53326	-6.11
u94g030cm	13/12/04	53352	-4.29
u94g040cm	14/01/05	53384	-1.20
u94g050cm	13/02/05	53414	-1.13
u94g060cm	10/03/05	53439	-2.65
u94g070cm	6/04/05	53466	-0.24
j94g08feq	01/05/05	53491	-3.34
j9al02skq	22/05/05	53512	-3.62
j94g10hqq	29/05/05	53519	-2.52
j94g10hqq	26/06/05	53547	-3.05

j94g11k1q	27/07/05	53578	-0.62
u94g120cm	26/08/05	53608	-2.33
j94g07p7q	09/09/05	53622	-4.62
u9i4020cm	1/10/05	53644	0.53
u9i4040cm	11/12/05	53715	-1.00
j9i405mhq	30/12/05	53734	-3.89
j9i406swq	22/01/06	53757	-3.14
j9i407lzq	23/02/06	53789	-6.70
j9i408cfq	13/03/06	53807	-1.80
j9i409djq	19/04/06	53844	-8.40
j9i410a2q	25/05/06	53881	-4.04
j9i411ubq	09/06/06	53895	-3.99
j9i412jrq	05/07/06	53921	-5.05
j9i413bwq	07/08/06	53954	-1.54
u9i4140cm	9/09/06	53987	-1.11
u9vg010cm	6/11/06	54045	0.67
j9vg02d0q	27/11/06	54066	3.60
j9vg03usq	20/01/07	54120	1.02
j9vg03w0q	21/01/07	54121	-0.76
u9vg040mm	6/03/07	54165	-3.18
u9vg060hm	25/04/07	54215	-2.81
u9vg070pm	28/05/07	54248	-4.02
u9vg080pm	7/07/07	54288	-1.21
u9vg090km	7/08/07	54319	-1.12
u9vg100cm	18/09/07	54361	-1.58
u9vg110om	6/11/07	54410	-2.95
u9vg120pm	2/12/07	54436	2.80
u9vg130pm	15/12/07	54449	-0.48
u9vg140pm	17/01/08	54482	1.74
u9vg150pm	28/01/08	54493	0.45
u9vg160pm	2/03/08	54527	-1.13
u9vg170pm	16/03/08	54541	-0.16
u9vg180pm	20/04/08	54576	0.81
ua5t010om	1/05/08	54587	-1.96
ua5t020om	13/06/08	54630	0.36
ua5t030nm	23/06/08	54640	-0.59
ua5t040om	31/07/08	54678	-0.93
ua5t050om	15/08/08	54693	-3.27
ua5t160om	24/09/08	54733	-3.07
ua5t180nm	19/12/08	54819	-2.87
ua5t270om	1/01/09	54832	-1.48
ua5t190nm	28/01/09	54859	-2.93
ua5t200nm	23/02/09	54885	-5.18
ua5t210mn	22/03/09	54912	-3.49
ua5t220om	3/04/09	54924	-4.07
ua5t280om	6/04/09	54927	-2.87
ua5t290om	10/04/09	54931	-1.53
ua5t300om	23/04/09	54944	-1.54
ua5t310om	25/04/09	54946	-1.39
ua5t320om	1/05/09	54952	-1.33
ua5t330om	7/05/09	54958	-1.40
STIS_SMOV	4/06/09	54986	-2.30
ACS_SMOV	14/06/09	54996	-0.62
ACS_SMOV	9/07/09	55021	-2.20
ACS_11501	24/07/09	55036	0.40