

Focus Variation and the Orbital Phase of Observations

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ABSTRACT

We report the effects of cyclic OTA length changes (“breathing”) on focus position for a variety of observational strategies. Special attention is given to the case of NICMOS coronagraphic observations of bright targets. These observations are generally made in pairs, with a large ($\sim 30^\circ$) spacecraft roll between the observations. We find that if the pairs are forced into the same orbit, there is on the average a 1.6 micron secondary motion between the observations. If the pairs are separated by an orbit, however, on average the focus variation is only 0.75 microns. The difference in average focus variation is even larger (a factor of four) if only the focus variation immediately after a spacecraft slew is considered. This result suggests that coronagraphic observations (as well as others very sensitive to focus) should be put in congruent parts of consecutive orbits.

1. Introduction

As HST orbits the Earth it is exposed to varying amounts of sunlight and Earthlight (both reflected and emitted). This variation in incident flux causes the telescope to expand and contract, generally with one cycle per orbit. This change in focal length causes a change in the measured focus, and is commonly called “breathing”.

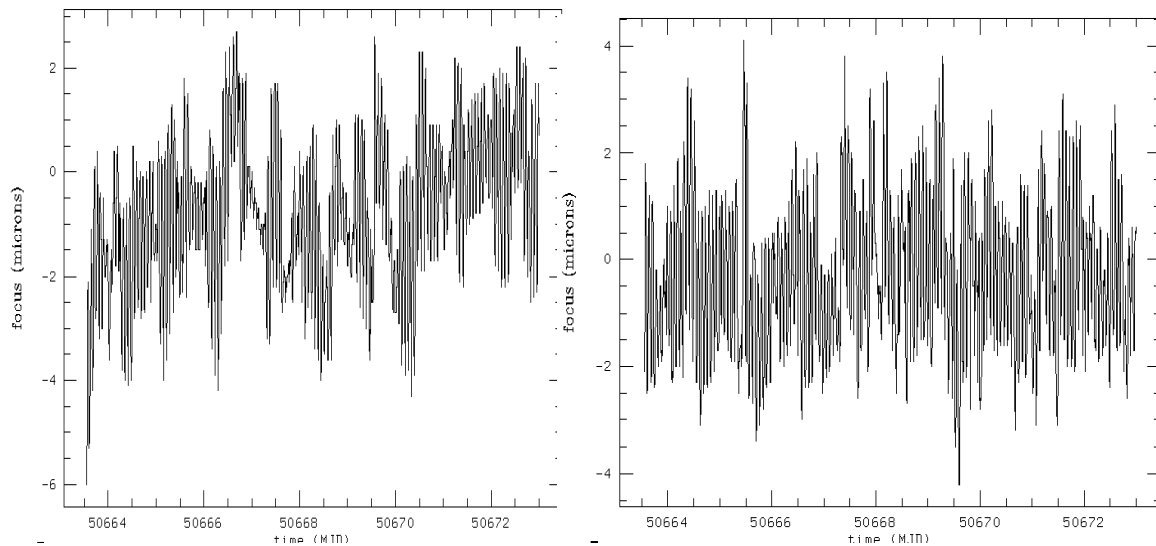
Several models have been developed to measure and predict the extent of focus deviations due to breathing. These are summarized in Hershey (1997). The simplest (developed by Pierre Bely) uses the temperature telemetry from the light shield near the four secondary supports. A model based on spacecraft attitude parameters (angle from the sun and the bright Earth, off nominal roll, etc.), here called the “analytical model”, does a much better job of fitting the slow excursions caused by a large change in attitude. A model using many temperature measurements (not just the four temperatures in Bely’s model) has been developed. In most cases (without unusually large focus excursions) it better describes the short- and long-term focus variations than the analytical model. Hershey’s analytical

model is very useful for its predictive capability: the other two models can only tell what the magnitude of the breathing was after the observations were made. Thus results in this paper are presented for identical analysis of both the analytical and the multi-temperature models. The large number of variables input to the analytical model prohibits a thorough a priori investigation of different scheduling situations.

2. Method

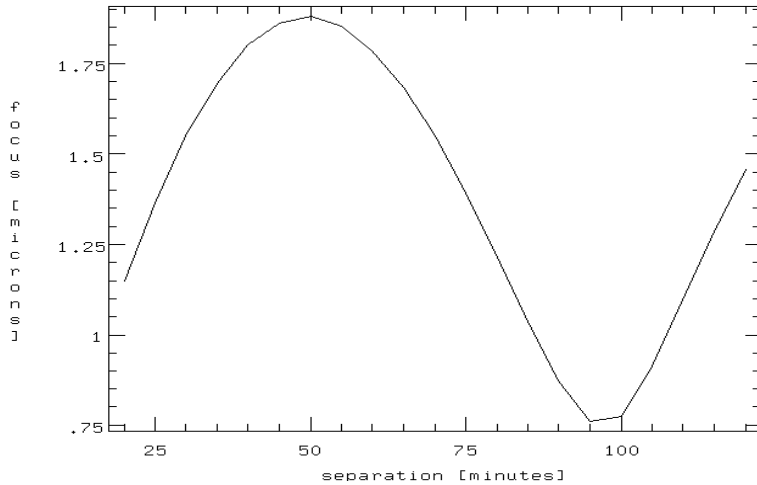
The models themselves are shown in Figure 1. The time period covered is from 3 August to 13 August 1997, a total of 9.5 days. The change in focus due to the HST orbital period is obvious but does not explain all the variations in the functions. There are jumps in both amplitude and average value at uneven intervals. These are explained by the changing aspect of HST when a slew is made to a new target. Bely's original ("4 temperature") model did not include these larger variations, but the two models used in this analysis do a pretty good job. Remember that there are no absolute measurements of the focus during this timeframe, however: such measurements are generally few and far between. This time period was chosen to cover that illustrated in Hershey (1997), to ease comparison of results.

Figure 1: Analytical (left) and multi-temperature (right) models of focus variations.



We determined the focus variation expected for various observation strategies by averaging the focus over the length of the individual exposures (10 minutes) and determining the difference between the averages for two exposures with varying separations. This was done at all model points: effectively, the observation template was moved through the entire focus model. The results are treated statistically (means and variances determined) since there is no general way to tell where in a breathing cycle the observations will occur.

Figure 2: Focus variation (in microns of secondary motion) between exposures separated by various times (in minutes).



The result for the entire model range is shown in Figure 2. As the two exposures occur further and further apart, their average difference first gets greater (reaching a maximum at half an HST orbit's separation) and then smaller (reaching a minimum at one HST orbit's separation). For two ten minute exposures separated by 30 minutes (roughly the situation when two coronagraphic observations are made in the same orbit) the difference in focus is just over 1.5 microns (secondary motion) while if the observations are separated by one HST orbit, the focus difference is 0.75 microns. Separations of more than one orbit have higher focus differences, with minima at integral HST orbits being less pronounced due to long-term variability. It is clear that the minimum in focus change due to breathing will be when the exposures are taken exactly one orbit apart.

3. Effect of slews

The high-amplitude, low frequency variations in the focus curves in Fig. 1 are due to HST slewing to a new target. There is some hysteresis in the system, and so the full model results are necessary to determine the breathing. There is no simple way to predict what the breathing variation will be following a slew-- it depends on what has gone on before.

The NICMOS coronagraphic observations of bright targets will start right after a slew to the target, so we have broken the focus models up into two orbit subsets. These follow a significant change in sun angle (i.e., a slew to a new target) after which HST stayed on that target for the entire two orbits (195 min.). There were 25 of these instances in the 9.5 day period investigated here.

Table 1 shows the ratio of average focus variation when ten minute long observations are separated by thirty minutes, to when they are separated by 96.5 minutes. This number can be thought of as the increase in average focus variation when observations are made in the same orbit, vs. observations made one orbit apart. The variation in the behavior after different slews shows the richness of the focus variations: focus variation is not a simple

function. The technique for minimization of the focus variation is also apparent in both models: pairs of observations made right after a slew will have four times the focus variation if they are forced into the same orbit as they will if they are put in consecutive orbits.

This factor of four (rather than the factor of two seen when the whole 9.5 day model time period is analyzed) is expected because the breathing right after a slew is measured only over a short period. The result from the whole 9.5 day period includes the variation due to simulated “observations” that span a slew, a situation that would not arise in actual operations.

Table 1. Ratio of average focus variation immediately after a slew, between observations separated by 30 min. and by 96.5 min. The average of these values is a factor of 3.9 for the analytical model, and a factor of 4.1 for the multi-temperature model.

Analytical	Multi-temp.	Analytical	Multi-temp
8.3	4.1	6.1	3.1
0.8	1.8	2.8	7.5
1.6	5.0	1.9	10.3
11.4	2.6	8.0	7.6
8.0	3.5	6.0	1.1
6.9	7.0	1.4	4.0
2.1	5.8	1.4	5.4
3.4	4.4	4.0	2.2
1.3	2.4	1.0	1.7
2.9	3.3	3.5	1.7
1.0	2.4	2.2	1.5
5.7	2.2	10.2	4.5
1.1	2.1		

4. Conclusions

The focus variation for exposures obtained in the same orbit will be (on the average) twice as large as the focus variation between the same exposures taken an orbit apart. The variation difference gets even higher if the analysis is limited to the time right after a spacecraft slew. In general the exposures separated by an orbit will have one quarter the focus variation of exposures taken in the same orbit, immediately after a slew.

NICMOS coronagraphic observations of bright targets (that are done with a pair of observations separated by a roll of 30° or so) will particularly benefit from having their halves scheduled at congruent parts of adjacent orbits. The breathing cycle repeats well over this short period, enabling substantial elimination of the focus variation.

5. Reference

Hershey, J.L. (1997): "Modeling HST Focal-Length Variations", SESD-97-01, STScI