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ACS PSF variations with temperatures

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ABSTRACT

We have used the HST ACS/WFC observations of a Galactic bulge field taken over a continuous interval of 7 days (Prop 9750) to investigate the possible dependence of the ACS focus with the external temperatures. This dataset allows us to investigate possible focus variations over timescales of a few hours to a few days. The engineering data related to the external temperatures for this duration show that the maximum temperature change occurred over the first 1.5 days. Among all the different temperatures recorded, the truss diametric differential and the truss axial temperatures are the only two temperatures which have the same timescale of variation as the PSF-width variations. The PSF-widths also strongly correlate with these two temperatures during this time interval. We empirically fit the PSF-width variations with these 2 temperature sensor values. This suggests that the focus has a similar dependence, and we recommend that this finding be followed up with the determination of actual focus values to check if the focus values indeed have the same correlation. If so, the temperature data can be useful in estimating the focus values, which can then be used to predict the PSFs to a first order.

Introduction

A good knowledge of the PSF is crucial for several science projects, ranging from detection of debris disks around nearby stars and detection of close binary companions, to determination of cosmic shear from weak lensing observations. This has prompted several studies recently for a better characterization of the ACS PSFs (Anderson et al.

2006, Rhodes et al. 2006). These studies indicate that the ACS PSFs in different filters and across the ACS field-of-view can be accurately predicted from the focus values. However, the determination of the focus itself relies on the measurements of good PSFs (taken in a single filter). Thus, it is necessary to devote some extra observing time to obtain PSFs of some isolated stars in order to determine the focus.

There has been several earlier attempts to determine the focus values directly from the temperature sensor data. The first attempt was made by Bely, Hassan and Miebach (1993) who used the FOC observations of an isolated star and the external temperature to empirically determine the dependence of short-term focus change with the temperatures. Observations of a single star were taken over several sequential orbits in two extreme orients, one at sun-angle near 90° in the CVZ, and the other at the anti-sun direction. They found that the focus oscillates with a period of one HST orbital period. This amplitide of the focus oscillation was found to correlate with the light-shield temperatures. They developed an empirical model for the same, now known as Bely's breathing model, which is now represented as (see Lallo et al. 2005):

$$SM = \text{Scaling factor} * (LS\text{-}MLS) + C \tag{1}$$

Where
SM is the secondary mirror displacement in microns
LS is the instantaneous mean of the four light-shield temperature sensor values
MLS is the mean of the LS over the previous orbit, and
C is a zero-point offset.
As shown by Lallo et al. (2005), Bely's breathing model holds for a range of secondary motions by appropriate choice of the constant C and the current value of the scaling factor is 0.7.

The focus change was further investigated by Hershey (1997), who studied the focal-length changes based on telescope attitude parameters as well as the one based on telescope temperature telemetry. It was found that the temperature-based model generally represents the observations somewhat better than the attitude-based model. The dataset used for this study was however sparse, and it was suggested that in order to improve the findings, it is necessary to use a dataset obtained over a continuous period of several orbits.

The observations of proposal 9750, which uses HST to monitor a Galactic bulge field over a continuous period of 7 days, thus provide an ideal dataset for this investigation. However, the focus determinations for all epochs of this entire duration would be a laborious and time-consuming task. So, as a first step, we use the width of the PSF as a proxy for the focus value, and investigate if some of the external temperatures strongly correlate with the PSF widths. Depending on the results, we then intend to followup this study with actual focus measurements.

Input Datasets

A. Science data

We use the 9750 dataset (PI: Sahu) where a rich field in the Galactic bulge was monitored continuously with ACS/WFC over a 7-day interval (2004 February 22-29), obtaining a total of 254 and 265 exposures in the V (F606W) and I (F814W) filters, respectively. For this analysis, we use only the F606W observations since (i) F606W observations are generally used for phase retrieval and (ii) the relation between the PSF and the focus change is better studied for the F606W filter. The sun angle of the telescope during the observations was within 59° to 53° which provide a reasonably moderate range of values for this study. The observations were taken with intra-pixel ditherings, and the resultant x,y offsets, roll-angle changes, and plate scale changes are described by Gilliland (ISR-TEL-2005-02; 2005).

Three parameters were used as possible proxies for the focus variations: (i) the FWHM of the PSF, (ii) the width to enclose 90% of the light in the PSF, and (iii) the width to enclose 95% of the PSF. We used 20 bright and unsaturated stars (but close to saturation so that the S/N is the highest), for the measurements. Since the field is extremely crowded, it is important to ensure that the stars chosen for the PSF measurements are sufficiently isolated. We chose relatively bright, isolated stars for which less than 3% of the light within 20 pixels comes from neighbouring stars. There is a linear correlation between all these 3 parameters, and for the final analysis, we chose the average FWHM for this investigation.

B. Engineering data

We collected all the engineering data related to the external temperatures during this interval. The engineering data consist of the following:

1. Mean of four Aft Light Shield temperatures: This is the mean of temperature sensor values T307, 308, 309 & 310. These are at 0, 285, 180, and 105 degrees respectively around the aft part of the HST light shield, which is the forward-most cylinder on HST, originating in the plane of the secondary mirror and extending forward. These particular sensors lie close to the plane of the secondary mirror. (For full details, see page 2-37 of the HST TCS Document.).

2. Truss axial differential: This is derived from the two rings of Forward Shell sensors described in #5 below; it is the difference between the forward ring and the rearward ring. The sense is not known (but the analysis presented here makes the sense clear).

3. Truss diametric temperature differential: This is the difference of the 4 warm side and the 4 cool side sensors described in #5 below. Sense is not known (but can be inferred from the obvious relationship presented here).

4. All Aft Shroud: This is a weighted mean of temperature sensors just inside the Aft Shroud, which is the large cylindrical section of HST containing the Science Instruments. Data from 14 sensors located in 6 rings around the Aft Shroud are used. (Pages 2-61 & 2-62 of HST TCS document).

5. All Forward Shell: The Forward Shell is the cylindrical tube, which sits between the light shield and the Aft Shroud and encloses the OTA/MT. These values are the mean of 8 different sensors, located in two rings, each with 4 sensors 90 degrees apart. The two rings lie 40 inches in from the front of the forward shell and ~40 inches in from the rear. (See page 2-38 in HST TCS Document).

6. All Light shield: This is the mean of the aft light shield sensors described in #1 above, and an additional 4 which sit in a ring near the front part of the light shield farther away from the OTA. (See page 2-38 in HST TCS Document).

7. 96 minute average: The instantaneous (5 minute sampled) mean of the 4 aft light shield temperatures are running-averaged over the previous HST orbit. This value is used in the Bely breathing model (Bely et al. 1993).

8. Breathing delta: The most easily modelled HST focus variation is an orbital effect which goes as the difference between the instantaneous aft light shield temperatures and the mean of these values over the previous orbit. An amplitude scale factor of 0.7 has been found to best fit most of the science instruments, past and present.

Analysis

The HST observations range from MJD ~53058.02 to 53064.98. Fig. 1 plots the variation of (i) mean light shield, (ii) breathing parameter (as described in Eq. 1), and (iii) the truss axial differential temperature sensor values during a time interval that includes one day before and after the 9750 observations. Clearly, the sense of the mean light shield temperature sensor values (which is used in the breathing parameter of Bely's model) is opposite to that of the truss axial sensors. Fig, 2 (a and b) show the variations of (i) mean light shield, (ii) forward-shell, (iii) truss diametric differential, (iv) the truss axial differential, (v) the breathing parameter, and (vi) the mean aft-shroud temperature sensor values during the observing interval. The orbital variations as well as the longer term variations are clearly seen in this figure.

All the temperature data show a gradual decrease of the temperature over the first 2 days, superposed on which is a clear orbital variation with a period of 96 min. The maximum temperature change occurred over the first 2 days of the observations, after which the average temperature (if we ignore the orbital variation) was stable. The temperatures increased again after the completion of the 9750 observations. An enlarged view of the variations is shown in Fig.3, which shows the orbital variations as well as the longer-term trend. We have mostly used the data from the first 2 days for this investigation during which the temperature excursion was the maximum.

Fig. 4 plots the PSF width for the duration of the 9750 observations. The maximum PSF variation also occurs during this initial 2 days, after which the change in FWHM is less than the noise. Comparison of this figure with Fig. 2 immediately shows that the timescale of the largest width variation is similar to that of the truss axial and truss diametric differential temperatures.

Any regular pattern in the PSF variation within each orbit is not obvious from this dataset. (This is unlikely to be due to our sampling even though we have only two to four F606W images in each orbit). The situation may be improved by determining the actual focus values through phase retrieval.

There is a strong correlation between the various widths described above, suggesting that any of the widths described above can be used a diagnostic; we have used the FWHM of the PSF in the final analysis. We tried to correlate the PSF widths with the various temperature measurements. As mentioned earlier, the timescale of variation makes it obvious that the width is most likely correlated with the truss axial and diametric temperatures. The best such correlations are shown in Fig. 5 and 6. In Fig. 5, the correlation between the PSF width and the truss diametric differential sensor value is given by:

$$\text{Truss diametric differential sensor value} = 3.5*\text{FWHM} - 15.6 \quad (2)$$

Fig 6 is a similar plot showing the dependence on the truss axial differential temperature, where the correlation can be expressed as

$$\text{Truss axial differential sensor value} = -7.3*\text{FWHM} + 40.05 \quad (3)$$

There is no clear correlation with other temperature diagnostics. The "breathing", plotted in Fig. 2 (represented by the all light shield temperature minus the average of such measurements in the previous orbit), also does not show any clear correlation with the PSF width. This suggests that, for a given pointing and continuous observing interval over a few days, the truss axial and diametric temperature measurements are better representative of the focus values, although we cannot rule out the fact that this may simply be due to the noise associated with the FWHM determinations.

Fig. 7 shows the variation of the PSF widths and the variation of the Bely's breathing parameter during the observations. The points in the bottom panel show the values of the breathing parameter at a time closest to the exposure used to measure the PSF width. There is always at least one temperature measurement during the length of every exposure, which shows that the temperature variation is smooth. This shows some indication that at least for single pointings over such time scales, the PSF variation may be more complex than that described by Bely's model. Since the FWHM determinations from WF observations are intrinsically more noisy (as compared to HRC observations), we suggest this be followed up with focus measurements.

The strong correlation between the PSF width and the truss axial and diametric differential temperatures would suggest that these temperatures could be used to predict the width of the PSF which, in turn, can be used as a proxy for the focus value, at least for continuous observations over a few days at moderate sun angles. The methods described by Rhodes at al. (2006) can then be used to predict the PSF shapes as a function of the position on the detector and the filter used.

There are several caveats, which must be mentioned, however. First, this analysis is confined to the measurements at a single epoch, so this possible correlation should be checked at a few other epochs. Second, the correlation presented here is valid only on a multi-orbit timescale, and does not track the variations in a single orbit. Furthermore, our sampling (two to five 6-min observation per orbit) seems inadequate for investigating any fine scale, inter-orbit variations.

Conclusion

There is some indication that the width of the PSF correlates with the truss diametric and axial differential temperatures on a multi-orbit timescale. This implies that the temperature data can potentially be used to predict the longer-term variation of the PSF, at least for a single pointing. If this same correlation is true in general (i.e. even at other time periods and at different pointings), this can potentially benefit many science programs.

We recommend that this finding be followed up with the determination of actual focus values (using phase retrieval method) to check if the focus values also have the same correlation (Di Nino et al. ISR, in prep.) If so, the temperature data can provide a first estimate of the focus values, which can then be used to predict the PSFs to a first order. This may also be followed up with (i) data from other similar proposals, and (ii) a calibration proposal where the maximum temperature differences can be simulated. This will show if the correlation of PSF with temperature is consistent over time.

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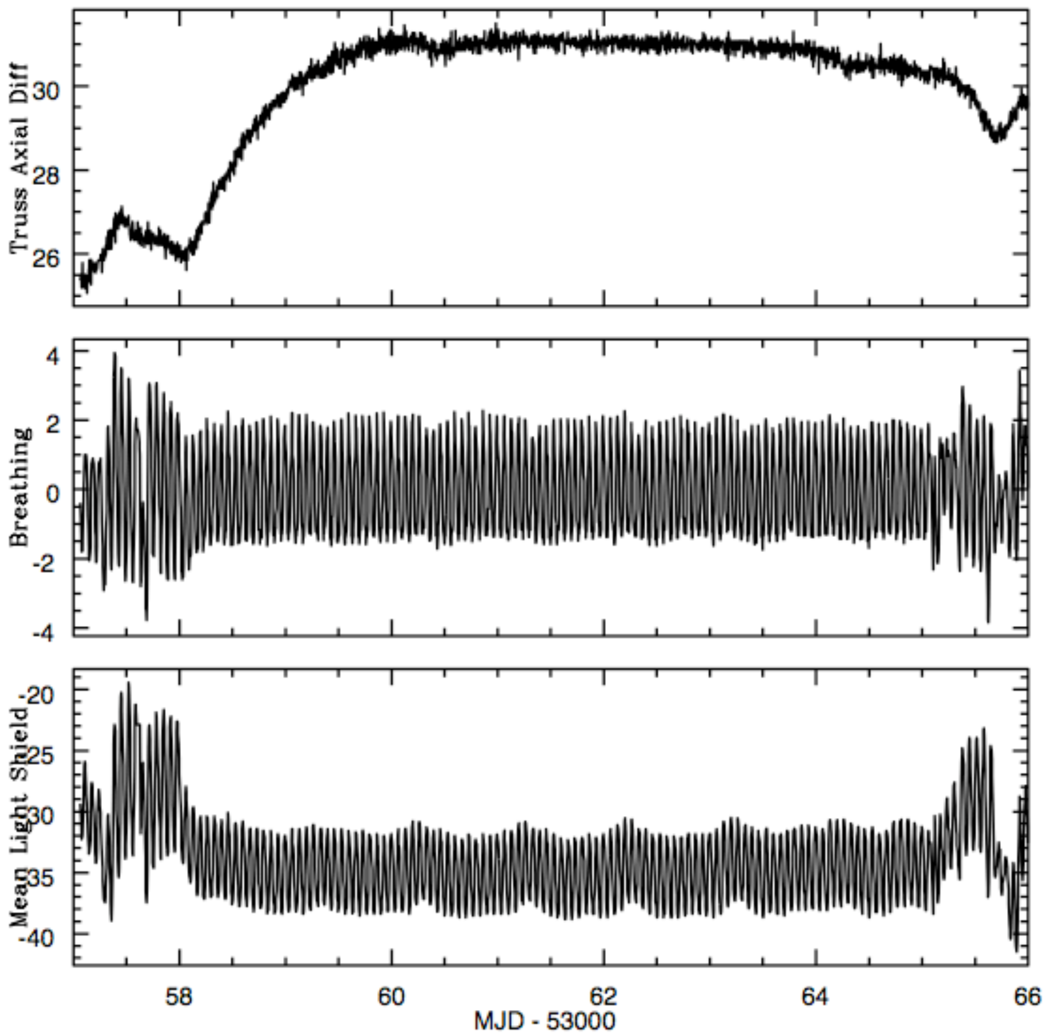
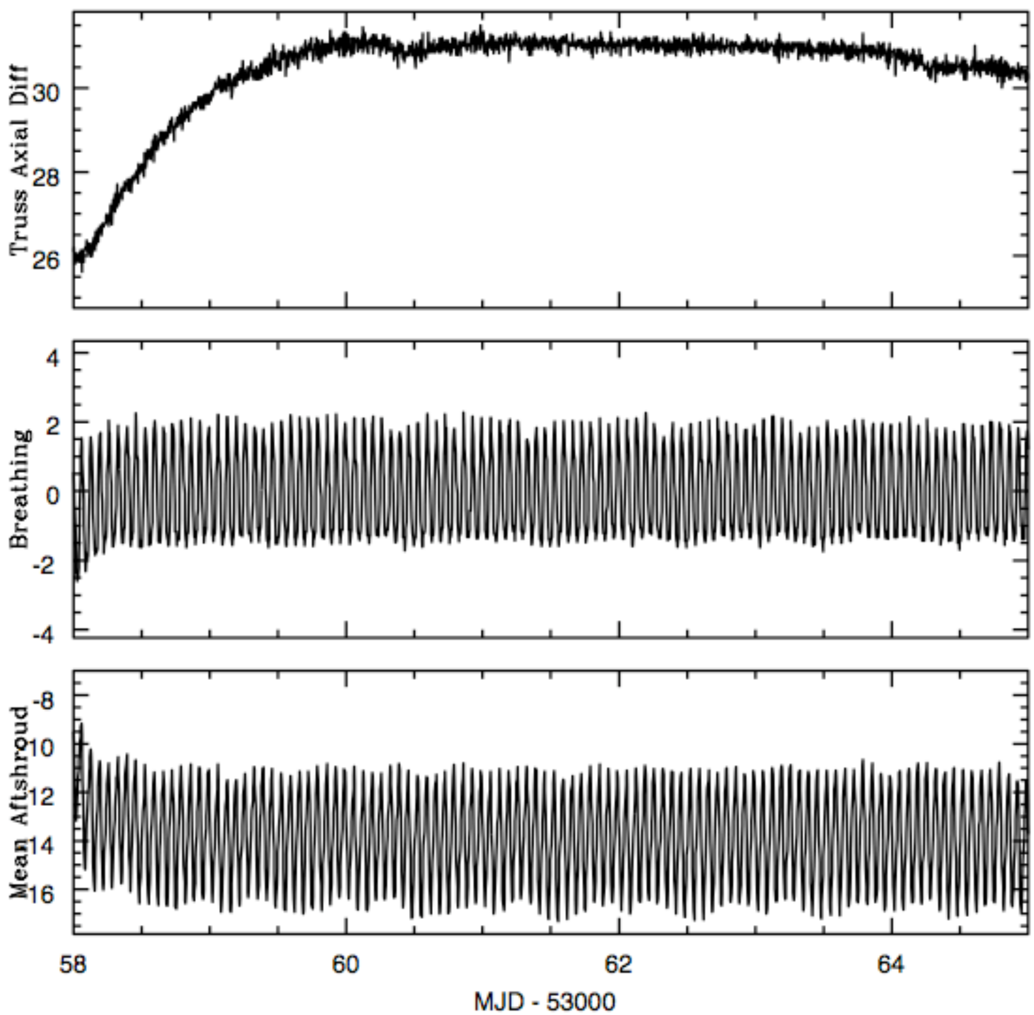


Fig.1. Variation of (i) mean light shield, (ii) breathing parameter, and (iii) the truss axial differential sensor values during the interval, which includes one day before and after the 9750 observations. The duration of 9750 observations span from day ~58.0 to 65.0. Clearly, the sense of the mean light shield temperature sensor values (which is used in the breathing parameter of Bely's model) is opposite to that of the truss axial sensors.



Fig, 2a. Variations of (i) mean light shield, (ii) forward-shell, and (iii) truss diametric differential temperature sensor values during the observing interval. The orbital variations as well as the longer term variations are clearly seen.

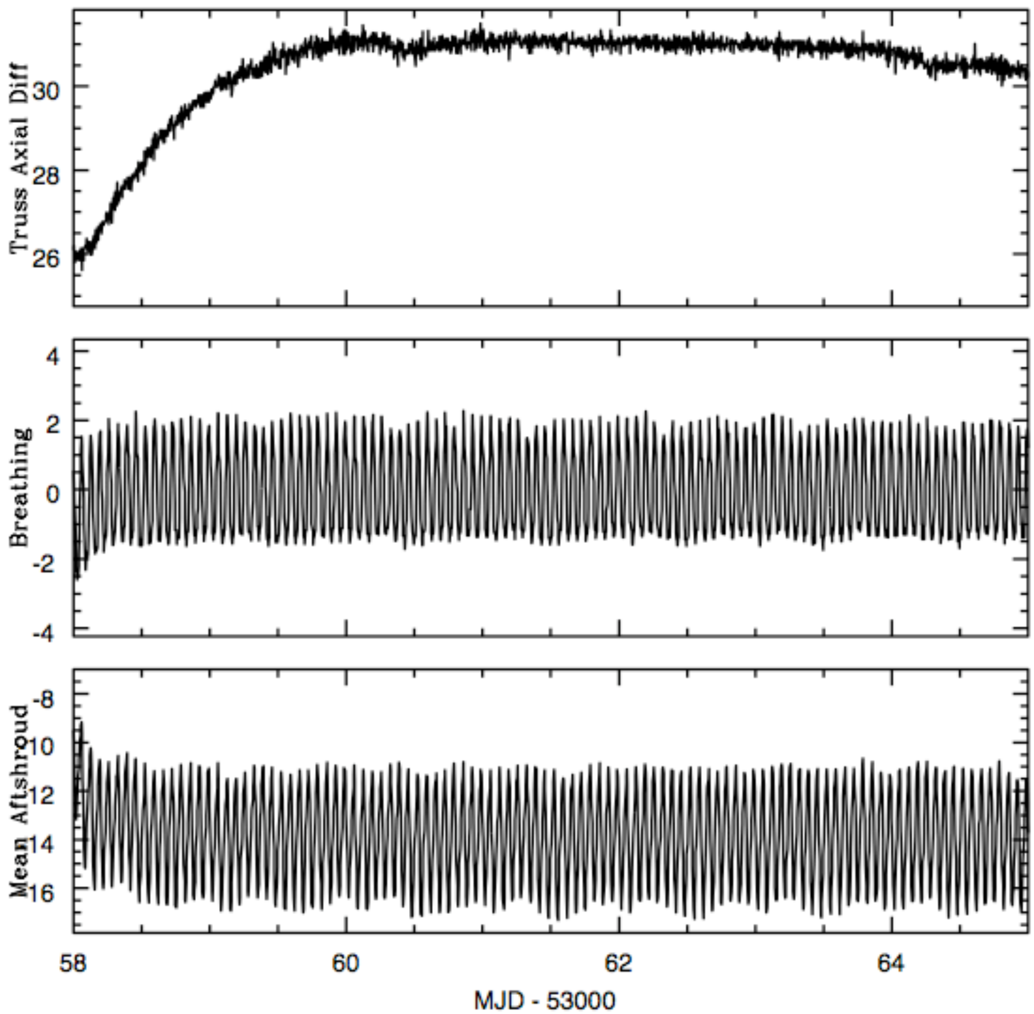


Fig 2b. Variations of (i) the truss axial differential sensor values, (ii) breathing parameter, and (iii) mean aft-shroud temperature sensor values during the observing interval.

Fig 3. Enlarged view of all the 6 parameters shown in Fig.2, but during the first two days of observations when the temperature excursions were the maximum.

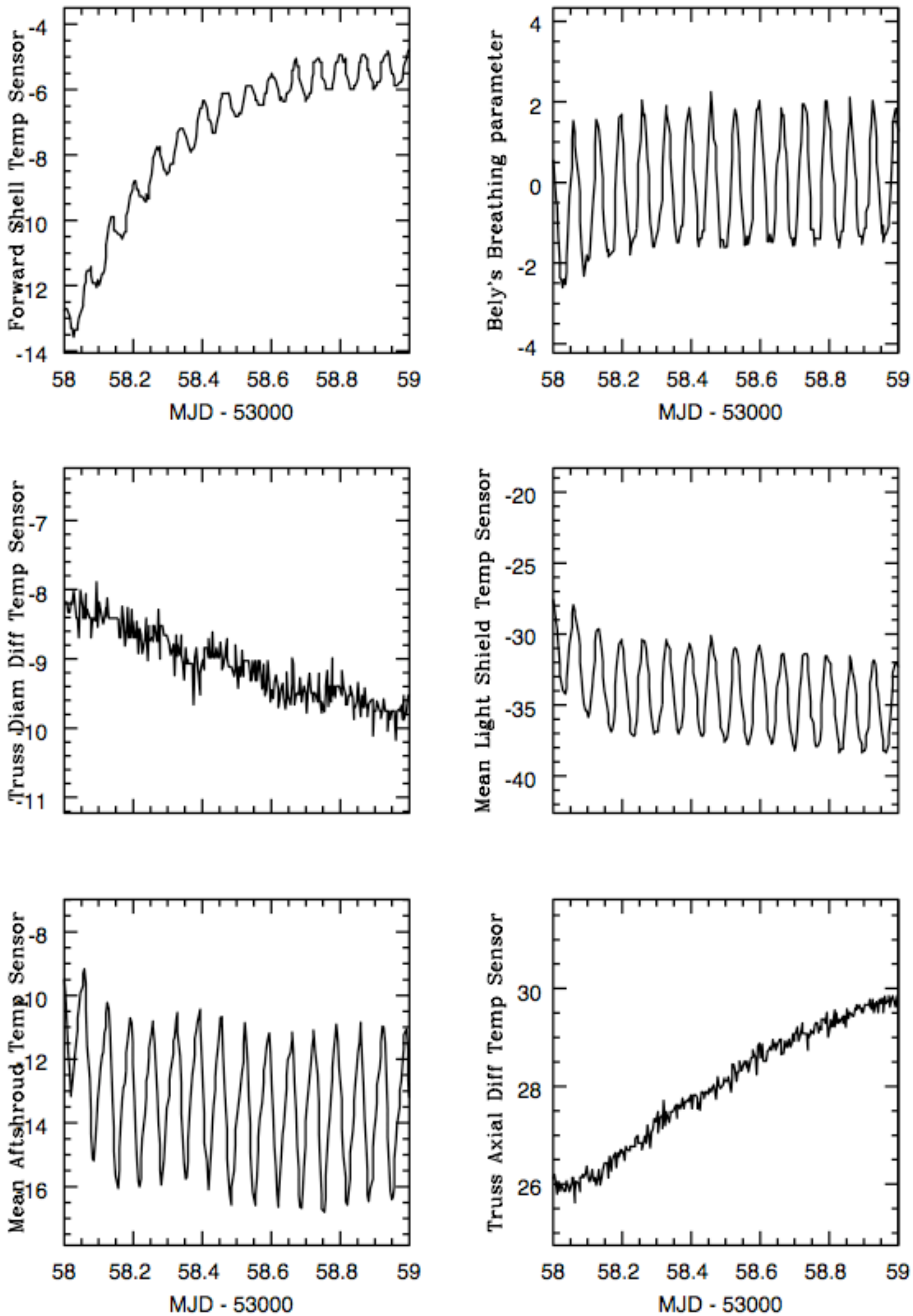
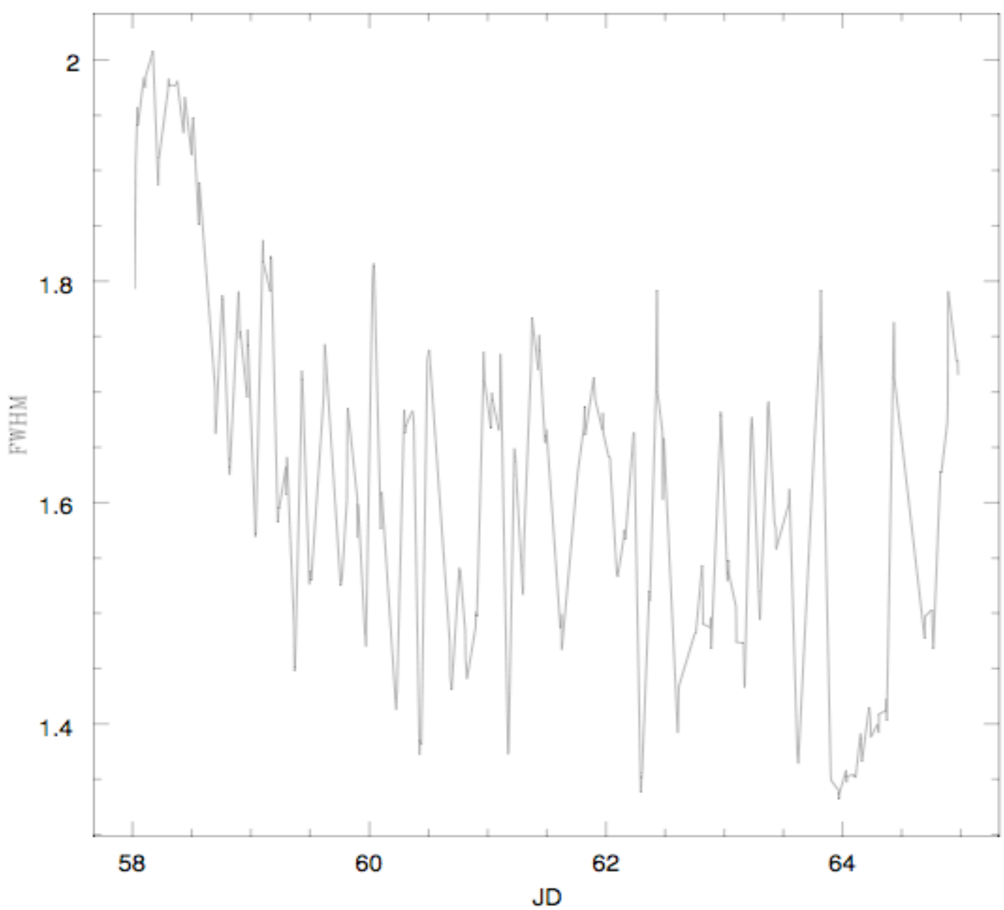


Fig. 4. The FWHM of the ACS/WFC PSF as a function of time during the 7-day period of 9750 observations. The width decreased by the maximum amount over the first ~1 day, after which the PSF variation is less extreme.



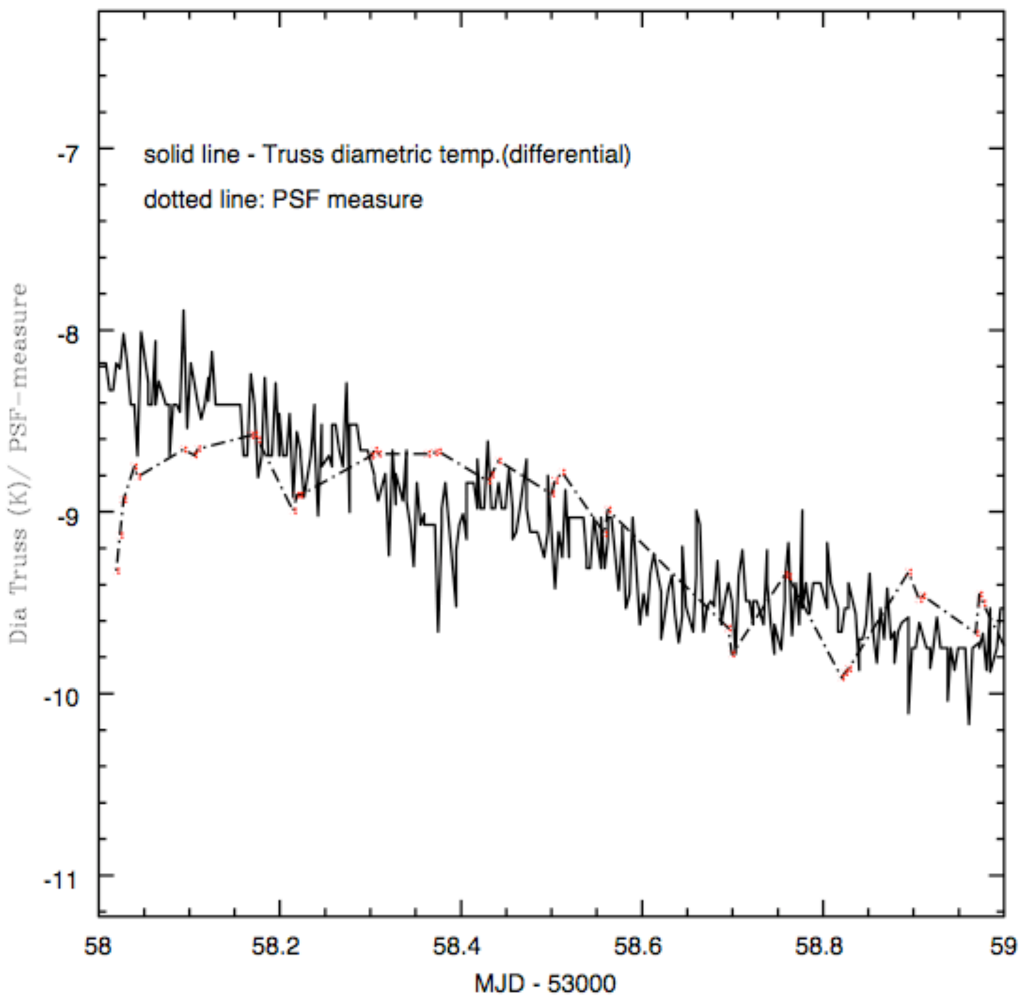
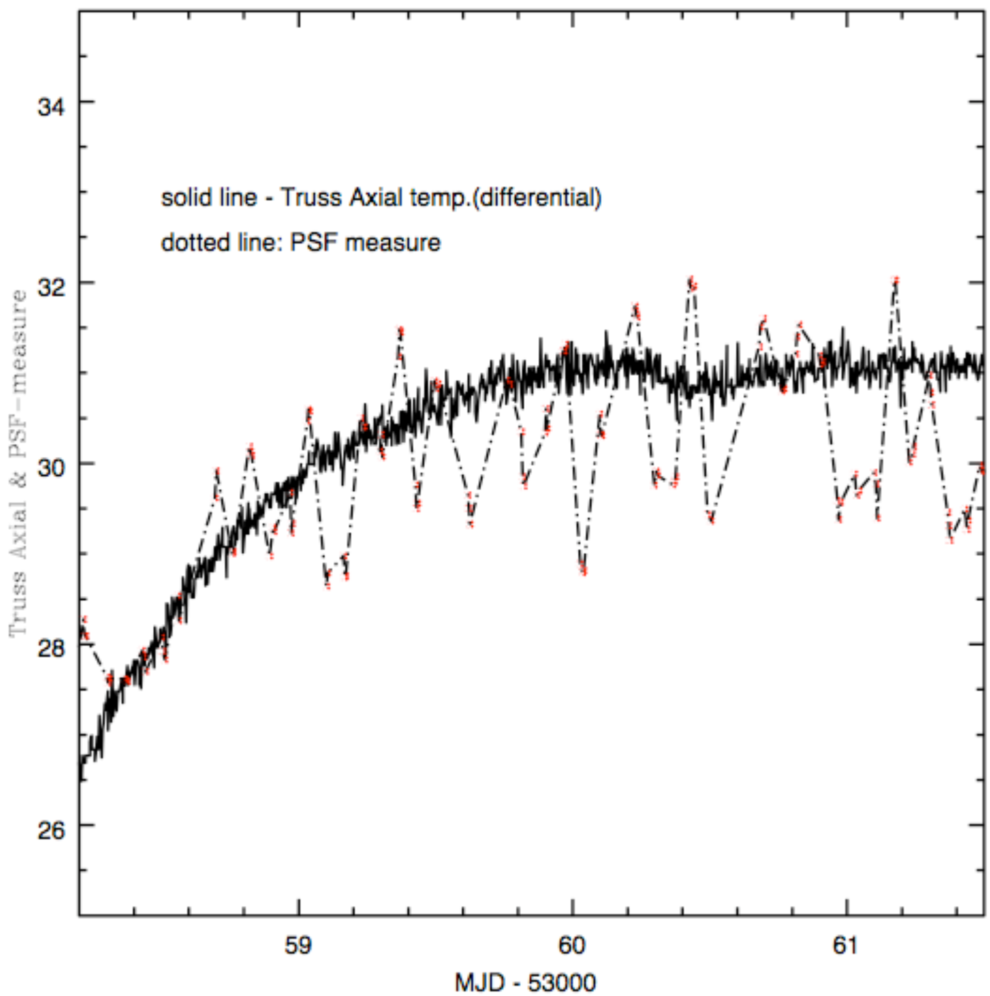


Fig.5. Diametric Truss differential temperature and the FWHM of the PSF as a function of time for the first 1 day of 9750 observations when the changes were the maximum. The PSF measure is defined as 3.5*FWHM - 15.6.

Fig.6. Truss axial differential temperature and the FWHM of the PSF as a function of time for the first ~3 days of 9750 observations, which include the range when the changes were the maximum. The PSF measure is defined as -7.3*FWHM + 42.05.



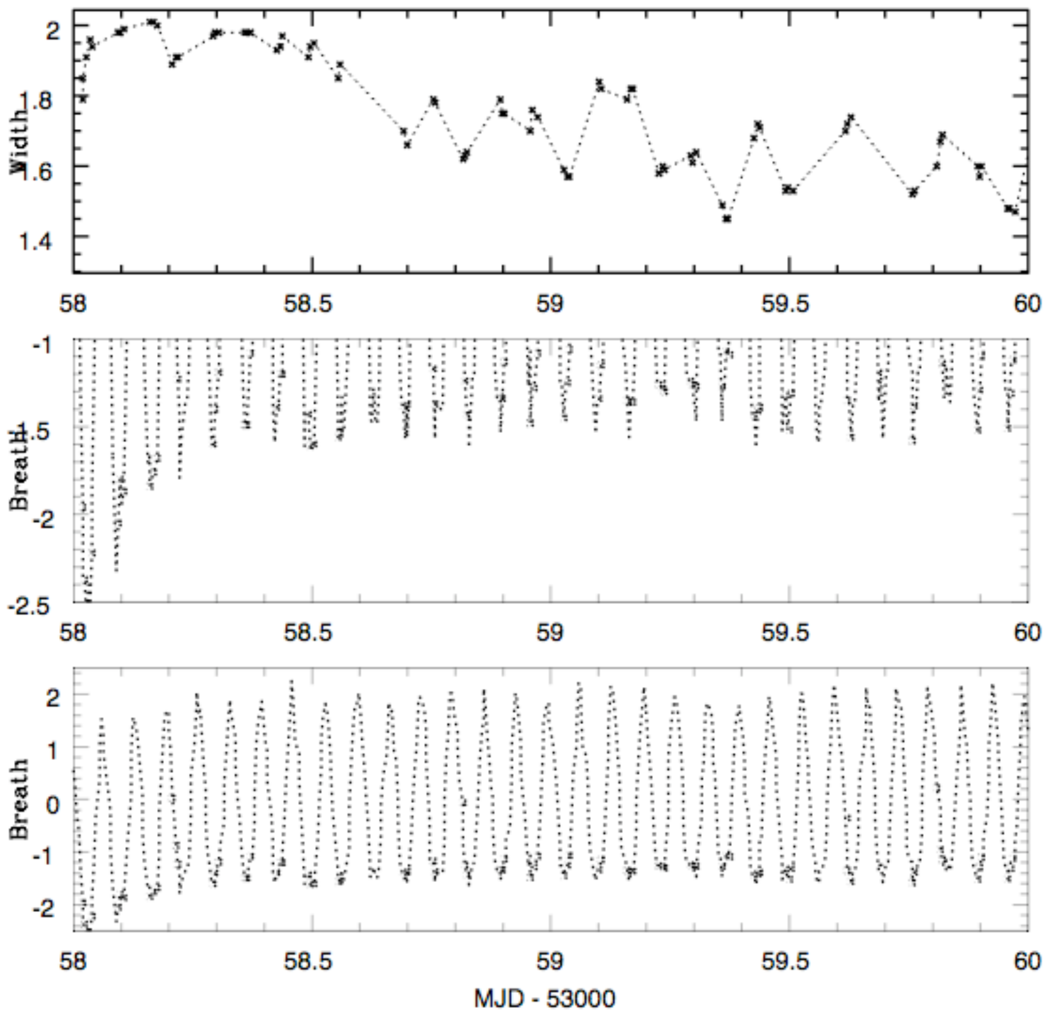


Fig. 7. The top panel shows the variation of the PSF widths and the bottom 2 panels show the variation of the Bely's breathing parameter during the observations. The middle panel is an enralged view of the bottom portion of the bottom panel. The points show the values of the breathing parameter at a time closest to the exposure used to measure the PSF width. There is always at least one temperature measurement during the length of every exposure, which shows that the temperature variation is smooth.

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