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The WFPC2 Photometric CTE Monitor

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ABSTRACT

The Charge Transfer Efficiency of the WFPC2 CCD arrays has been monitored since the instrument's deployment aboard HST in 1993. Since then a significant increase in CTE loss has been observed.

We examine photometric data from 28 April 1994 to 11 February 2001. The CTE loss appears to be growing worse in a linear fashion with time. The results from the latest set of observations show that CTE loss has reached a level of 53% in the worst case scenario.

Introduction

The WFPC2 camera contains four CCDs, and each CCD array consists of 800x800 pixels arranged in rows and columns. Each pixel receives photons, which are converted to electrons. These electrons are then passed from pixel to pixel along the columns (Y-axis or parallel axis) to the shift register, which is then read out by passing the electrons along the shift register (X-axis or serial axis). In each case, but more so for the Y-axis transfers than the X-axis transfers, not all the electrons are passed along, hence a loss of transfer efficiency. This loss depends on several factors, such as the position on the chip, the level of the background, the number of counts of the target(s), and epoch. Several previous studies have examined this CTE loss for point sources (Whitmore and Heyer 1997; Whitmore 1998; Casertano and Mutchler 1998; Riess et al. 1999; Whitmore et al. 1999; Baggett et al. 2000; Dolphin 2000; Schultz et al. 2001), and three of these (Casertano and Mutchler 1998; Whitmore et al. 1999; Dolphin 2000) have developed formulae to correct for the CTE loss in WFPC2 data. Further studies have researched CTE in extended sources (Riess 2000), and particularly faint sources (Whitmore and Heyer 2001).

The cause of the CTE loss appears to be radiation damage (Janesick et al. 1991), which accumulates with time. This effect is rather serious for space-borne detectors such as those of WFPC2, and that of any other present or future HST instruments such as NICMOS, STIS, ACS, and WF3. As future cameras will have larger CCDs with more pixels, the impact of CTE loss over the whole detector is potentially larger.

The CTE monitor observes the rich cluster Omega Centauri (NGC 5139) every six months. The purpose is to measure the CTE loss of the WFPC2 CCDs regularly, to provide data to adjust the correction formulae if necessary, and to observe the rate of increase of CTE loss over time and determine if this increase remains linear or accelerates. This has been done with data obtained from the calibration proposals 7630, 8447, and 8821 and will be continued in Cycle 10 in proposal 9254.

Data

CTE monitor data has been taken since April 1994. Table 1 provides a brief summary of the data volume obtained for this project to date.

Table 1. CTE Monitor Data Collection.

Dates	Filter	Gain	Exposure	Nominal Preflash	Average Backgrounds (DN; 8/99-2/01)
3/98, 8/98, 2/99, 8/99, 3/00, 8/00, 2/01	F439W	15	80 sec	none	0.035
8/99, 3/00, 8/00, 2/01	F555W	15	2 sec	none	0.014
3/98, 8/98, 2/99	F555W	15	16 sec	none	-----
8/99, 3/00, 8/00, 2/01	F555W	7	16 sec	none	0.141
8/99, 3/00, 8/00, 2/01	F555W	7	16 sec	20 electrons	3.933
8/99, 3/00, 8/00, 2/01	F555W	7	16 sec	50 electrons	8.636
8/99, 3/00, 8/00, 2/01	F555W	7	16 sec	200 electrons	32.43
6/96, 3/98, 8/98, 2/99, 8/99, 3/00, 8/00, 2/01	F814W	15	100 sec	none	0.496
4/94, 7/94, 2/95, 4/95, 8/95, 6/97, 3/98, 8/98, 2/99, 8/99, 3/00, 8/00, 2/01	F814W	15	14 sec	none	0.052
6/96, 8/99, 3/00, 8/00, 2/01	F814W	7	14 sec	none	0.117
8/99, 3/00, 8/00, 2/01	F814W	7	14 sec	20 electrons	3.713
8/99, 3/00, 8/00, 2/01	F814W	7	14 sec	50 electrons	11.01
8/99, 3/00, 8/00, 2/01	F814W	7	14 sec	200 electrons	31.57
8/99, 3/00, 8/00, 2/01	F814W	7	14 sec	1000 electrons	230.6

Analysis

Omega Centauri has been observed at the dates, in the filters, and with the gains and exposure times shown in Table 1 above. Each observation was taken with the field centered once in the WF2 chip, and once in the WF4 chip, thus rotating the field by 180 degrees with regards to the direction of readout and allowing the same stars to be observed on different positions on the chip, which allows a differential measurement of the CTE effect. The data reduction was performed using STSDAS tools, such as DAOFIND, METRIC, and DAOPHOT. Stars are identified in both WF2 and WF4 fields for the same observation set, and photometry is performed on those stars that are common to both fields. The differential measurements from the two fields yield the CTE loss for the Y-axis and the X-axis. The measured stars are then divided into bins according to their counts (20-50, 50-200, 200-500, and 500-2000 counts) for each observation set and plotted to show the increasing CTE loss with increasing row and column number on the chip for both Y-axis and X-axis, respectively (see example in Figure 1). After completing this for all observation sets the data is gathered and plotted as CTE loss vs. time (Figures 2 through 5).

As an example Figure 1 shows three plots for F439W, illustrating the increase of CTE with position on the chip. The throughput ratio is plotted against the difference in position on the chip. For both axes, but more so for the Y-axis than the X-axis, the CTE loss increases the further away the target is from the readout, i.e. higher columns and rows require more transfers, hence more chances to lose electrons. The top plot shows this for the Y-axis, the middle plot for the X-axis, and the bottom plot shows the distribution of counts in the sample. These plots are created for all observations sets.

Figures 2 through 5 show the CTE loss increase for all observed filters and gains, each Figure for one of the count bins. The CTE loss in percent over 800 pixels is plotted against time (in MJD). The general trends we can see are:

- CTE loss decreases with increasing counts of the targets. The plots for the higher count bins show less CTE loss, as do longer exposures.
- CTE loss decreases with increasing background. Filters with higher backgrounds show less CTE, as do preflashed exposures.
- CTE loss is largest for short (F439W) and long (F814W) wavelengths, and less so for intermediate (F555W) wavelengths, which is due to the differences in background level.
- CTE appears to increase linearly with time.

The Figures include measurements for preflashed exposures in two filters. We did these experiments for two filters (F555W, F814W). The preflash was accomplished by obtaining an internal flat field with F502N just prior to the Omega Centauri observation. This increased the background, increasingly so with more preflash, which decreased the CTE loss as expected. Higher background, however, also increases the noise level.

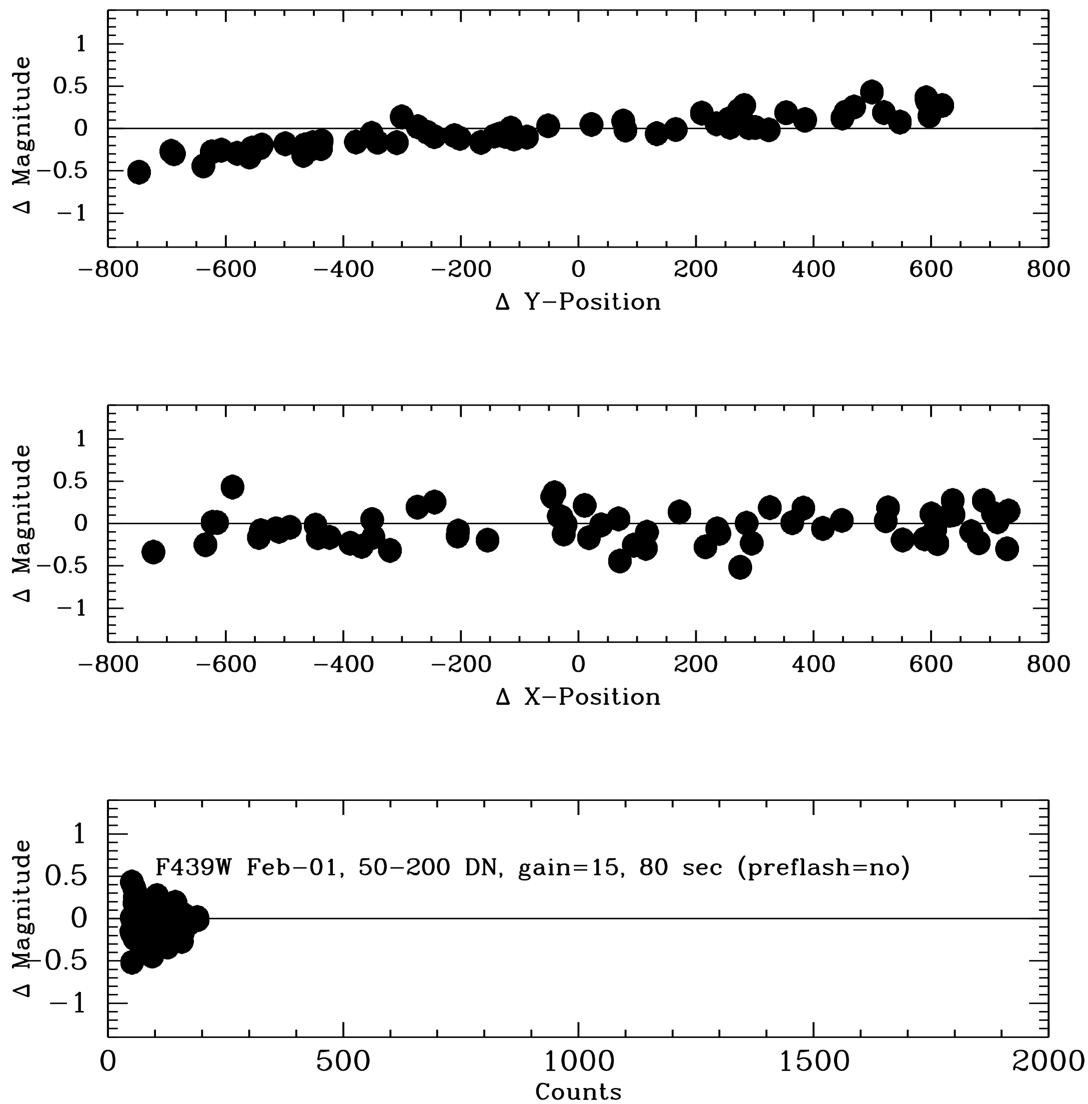

Figure 1: Magnitude difference vs. position difference for the 50-200 count bin of F439W. The plots show this for the Y-axis (top) and the X-axis (middle). The bottom plot shows the distribution of counts in the sample vs the magnitude difference.

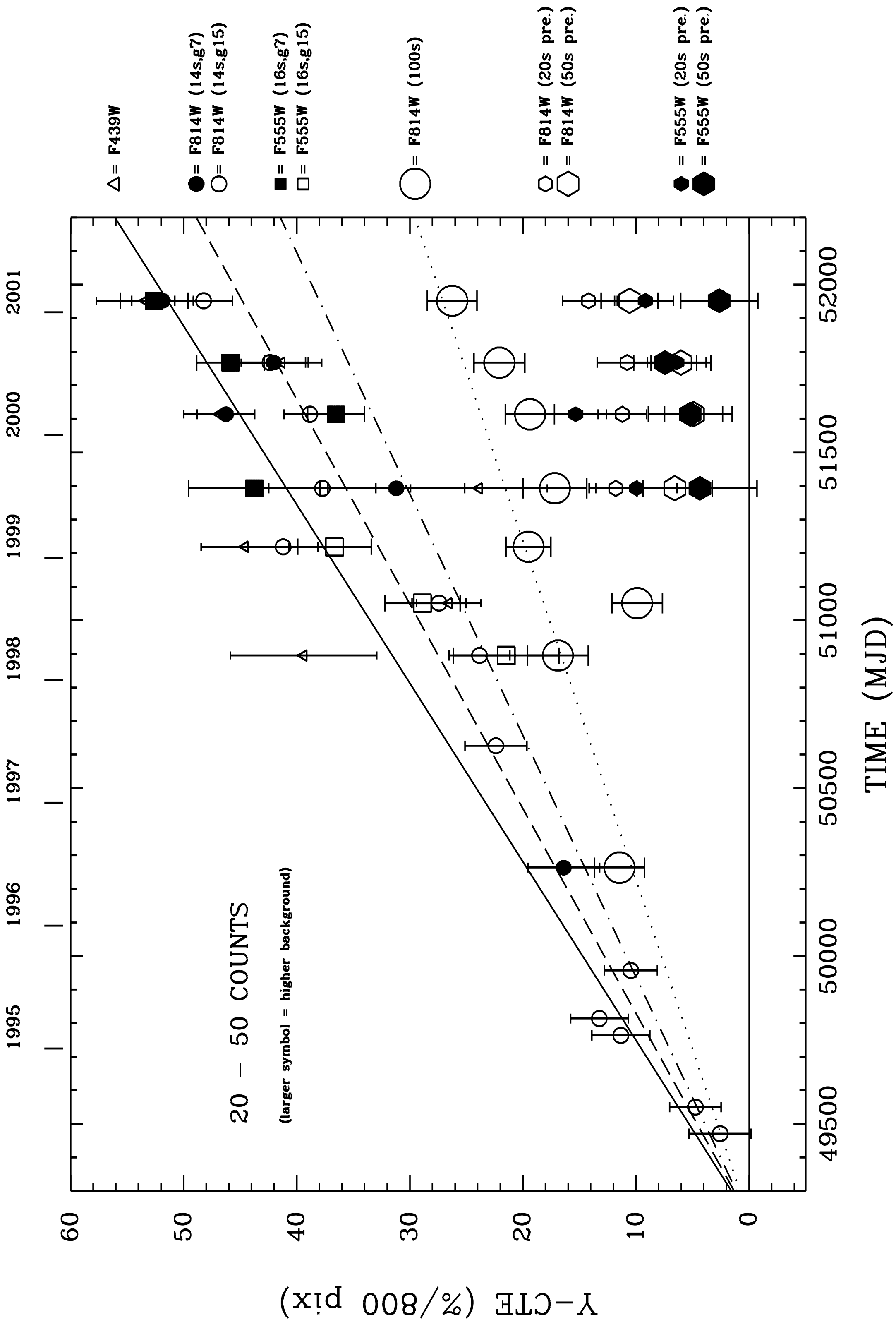

Figure 2: CTE loss in percent over 800 pixels against time (in MJD) for stars with 20 to 50 counts.

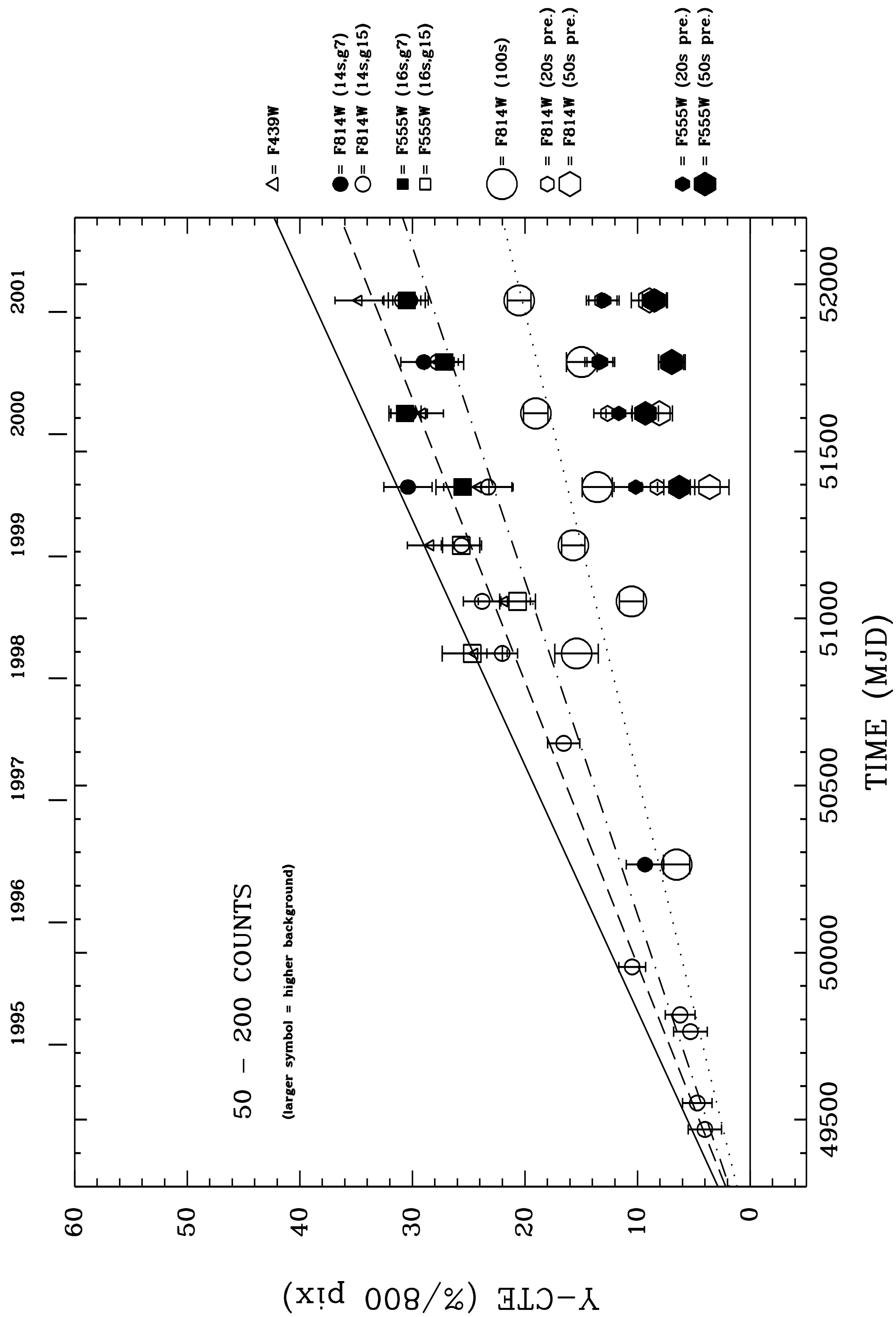

Figure 3: CTE loss in percent over 800 pixels against time (in MJD) for stars with 50 to 200 counts.

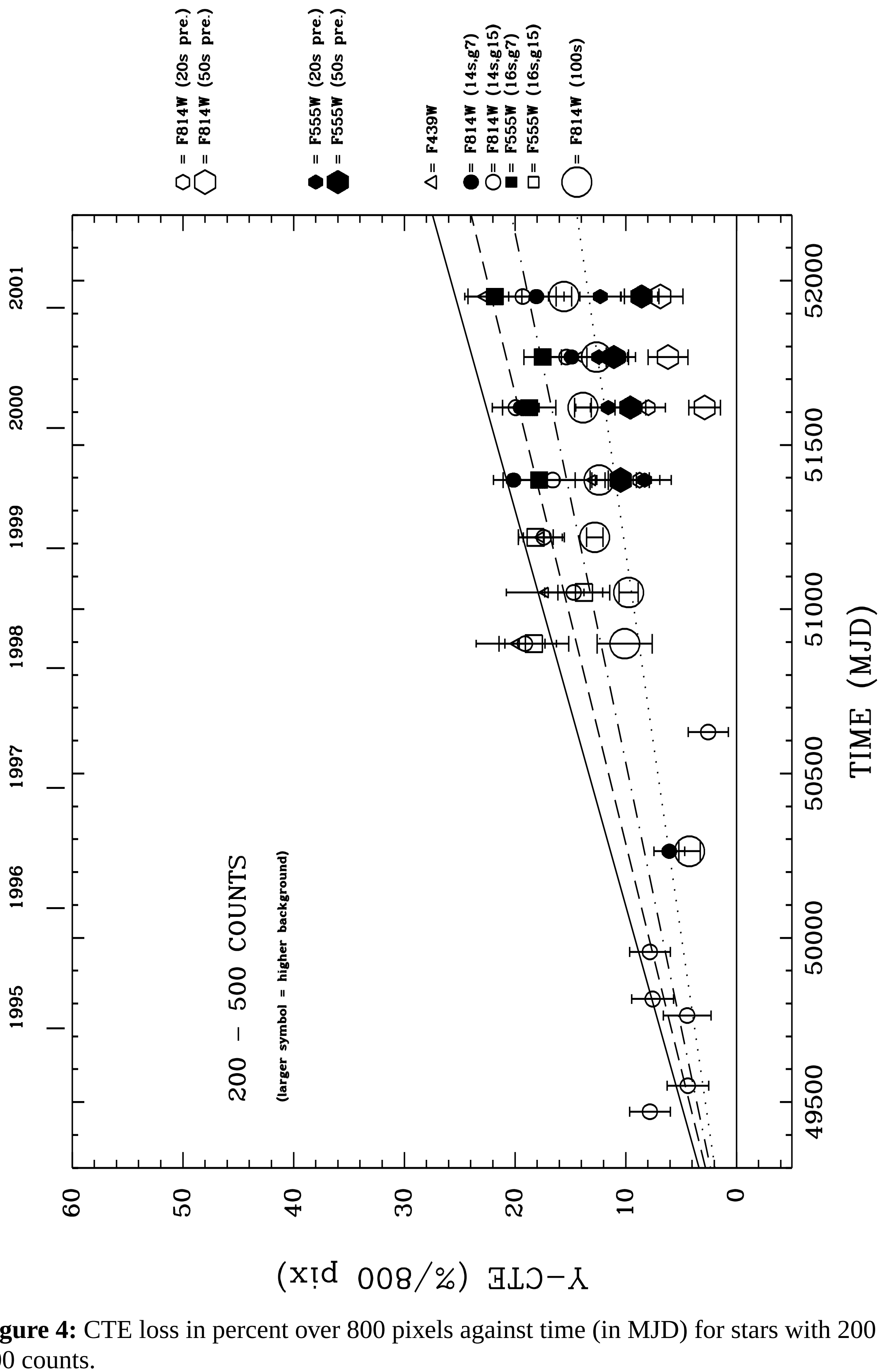

Figure 4: CTE loss in percent over 800 pixels against time (in MJD) for stars with 200 to 500 counts.

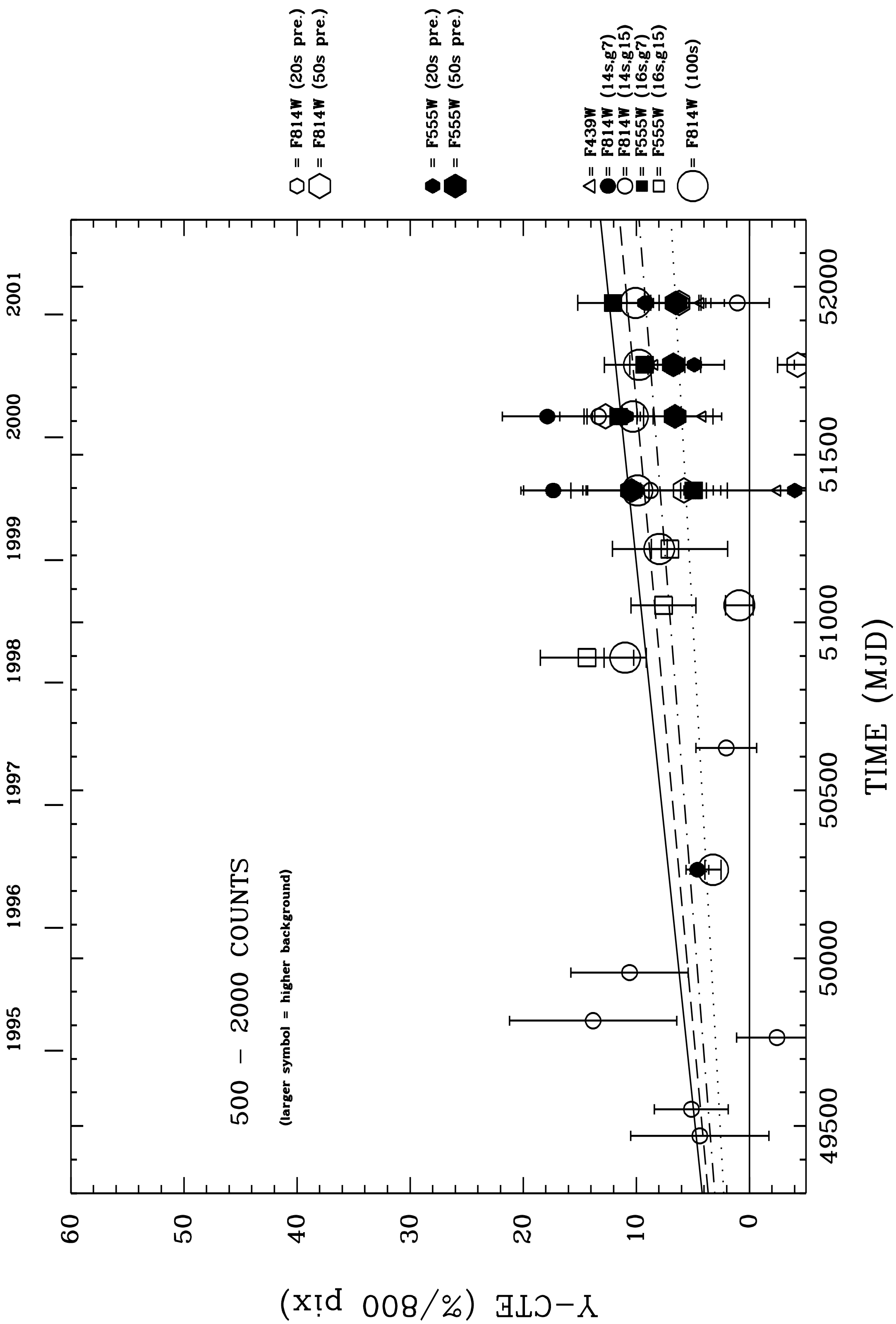

Figure 5: CTE loss in percent over 800 pixels against time (in MJD) for stars with 500 to 2000 counts.

One curiosity was observed, especially in the lower count bins where CTE loss is more pronounced. It appeared that the CTE loss was less in the fall (August) measurements, than in the spring (February or March) measurements. It also appeared that the background light is systematically somewhat higher in the fall than in the spring, which would account for the difference. After some digging an interesting fact came to light. The observation logs show that the parameter SUNANGLE, the angle between the sun and the V1 axis, is lower in August (around 85 degrees) than in March (122 degrees). Also, SUN_ALT, the altitude of the sun above the Earth's limb, is larger in August (mostly positive) than in March (always negative). This explains the slightly higher background in the fall, and therefore the somewhat lower CTE loss at that time.

Linear or Accelerating CTE Loss?

To answer the question as to whether CTE loss increases linearly or accelerates with time we did two different fits to the dataset with the longest baseline, which is F814W at gain = 15. The data was first fit with a linear fit, then with a second order polynomial. Figure 6 shows the result. In Table 2 we also include the details of the fits, which show that the chi-square of the linear fit is smaller than the the one for the second order fit. Furthermore, for the polynomial fit the second order term contributes only about 5% to the CTE loss. We conclude that CTE loss increases linearly with time, and that any possible acceleration is statistically insignificant at present. This will be monitored in the future and any changes will be reported.

Table 2. CTE Data Fitting Parameters for F814W Gain = 15 (Figure 6). X is the differential Modified Julian Date (MJD-49470).

Fitting Type	Fitting Equation	Chi-square
Linear	3.68 + 0.0206361 X	1.46
2nd order polynomial	4.27 + 0.0187192 X + 0.0000008 X**2	1.61

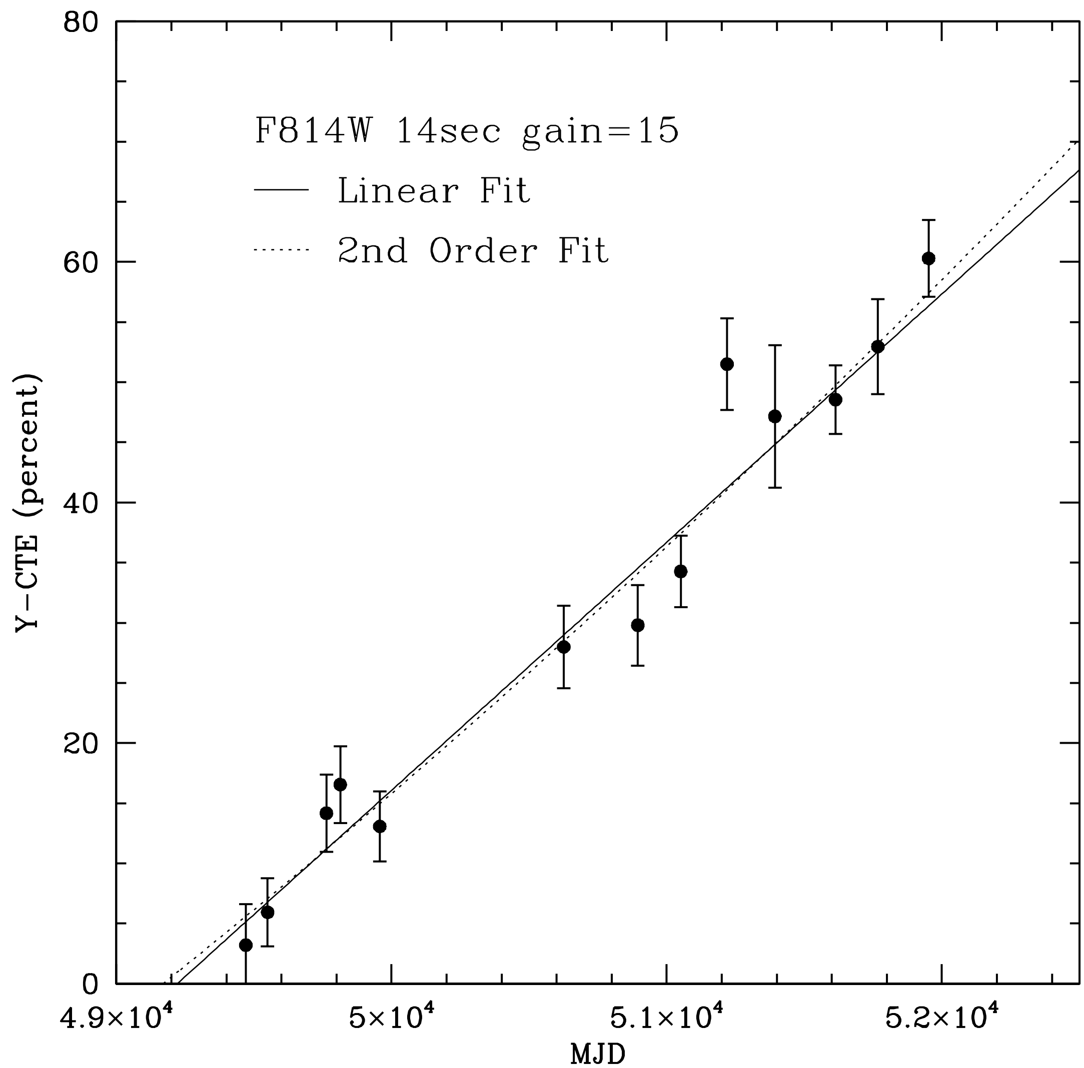

Figure 6: Linear and quadratic fits to F814W 14sec CTE data.

Conclusions

The above data show that the CTE loss appears to increase linearly with time, and that CTE loss is less for higher backgrounds and higher target counts, which among other things explains finding less CTE loss for preflashed exposures, as well as middle range wavelength filters.

The CTE loss has increased to 53% for the worst case scenario (F439W), i.e. faint stars on a very faint background at Y=800. However, typical WFPC2 exposures are much longer than these short calibration images, resulting in higher backgrounds and higher target count rates, and therefore experiencing significantly lower CTE loss.

Recommendations

The CTE monitor program will be continued in Cycle 11, and future updates to Figures 2 to 6 will be issued in ISRs and at AAS meetings.

Observers can mitigate the effects of CTE on their observations by heeding the following:

- Avoid excessively short exposures (i.e. avoid low background).
- Place small targets near read-out amplifier (e.g. at pixel X,Y ~ 150).
- Preflashing may be beneficial in certain situations.
- Apply corrections after observations.

Future Plans

Further ISRs will be issued discussing the preflashed CTE Monitor data, and comparing the results to the correction formulae available to determine the usefulness of these preflashes. We will also continue to incorporate new data as it becomes available, as well as examine in more detail the results from the other filters.

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