CHANDRA
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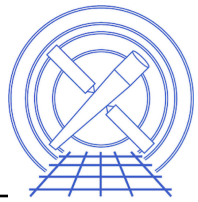

Date: September 21, 2021
From: John ZuHone and the ACIS Operations Team
To: Chandra Operations Team
Subject: Deciphering the Causes of the Anomalous Increase in Belt ECS Cold Time Between Epochs 85 and 86

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1 Abstract

The ACIS External Calibration Source data are grouped into epochs. The most recent completed epoch, epoch 86, had a much larger percentage of "cold" calibration data, defined as data taken when the ACIS focal plane temperature is less than a specified value (currently -117.2 °C) than the previous epoch 85. The purpose of this memo is to identify possible reasons for this difference.

2 Introduction

The External Calibration Source (ECS) on the *Chandra* spacecraft Integrated Science Instrument Module (ISIM) has served as the primary method of calibrating the ACIS instrument since launch. During passage through the radiation zones, the ISIM position is set so that HRC-S is in the focal plane, which places the ECS in view of ACIS. Thus, ECS measurements have typically been taken in radiation zones, though more recently (as of this writing in the summer of 2021) ECS measurements have also been taken during the science portion of the orbit.

The spectral calibration of ACIS is most accurate at low focal plane (FP) temperatures due in part to the effect of increased charge transfer inefficiency (CTI) at higher temperatures, thus it is desirable to keep the ACIS FP temperature as cold as possible during ECS measurements. At the time of writing, "cold" ECS measurements are defined as those which have a maximum FP temperature of -117.2 °C.

For purposes of calibration, ECS measurement data are grouped into "epochs", currently of 90 days. The two most recent completed epochs as of this writing are:

- Epoch 85: 2021:032 - 2021:120 (1 February 2021 - 30 April 2021)
- Epoch 86: 2021:121 - 2021:212 (1 May 2021 - 31 July 2021)

Table 1: Total and Cold ECS Time in Epochs 85 and 86

Epoch	All Radzone Time (ks)	Cold Radzone Time (ks)	Fraction (%)
Both legs			
85	613	145	24
86	421	192	46
Descending leg			
85	463	116	25
86	371	167	45
Ascending leg			
85	150	29	19
86	50	25	51

Epoch 86 had more cold time in radzone ECS measurements than epoch 85, both in terms of amount and fraction of total time. This is summarized in the first two rows of Table 1.

If one considers these quantities by separating ascending leg vs. descending leg ECS measurements (the remaining four rows of Table 1), the fraction of cold times in epochs 85 and 86 are very similar to the above fractions, ∼20-25% vs. ∼45-50%, respectively, in both legs. In what follows, we argue that this significant discrepancy in cold time can be accounted for in terms of the spacecraft attitude both previous to radzone entry and within it.

3 Analysis

We attempt to understand the difference in the amount of cold time between Epochs 85 and 86 by examining the evolution of the FP temperature during every radiation zone passage in each epoch. We also examine what we expect to be the main drivers of the FP temperature during the radiation zone passage. Like most ACIS components, the ACIS FP is heated up by sunlight most significantly at tail-Sun pitches, as the ACIS radiator shade and the back of the ISIM warm. The FP is also sensitive to Earthshine in the ACIS radiator field of view, which is most pronounced when the solid angle of the Earth is very large and thus when *Chandra* is at low altitudes, such as during radiation zone passages.

Figure 1 shows the ACIS FP temperature (top row), pitch angle (middle row), and Earth solid angle (bottom row) for every radiation zone passage in epochs 85 (left panels) and 86 (right panels). The times for each curve have been shifted so that the time of perigee is at $t = 0$. The FP temperature and the pitch have been obtained from the `cheta` engineering telemetry archive, and the Earth solid angle is a derived quantity which is computed from the `acis_taco` Ska package which is a function of the *Chandra* ephemeris

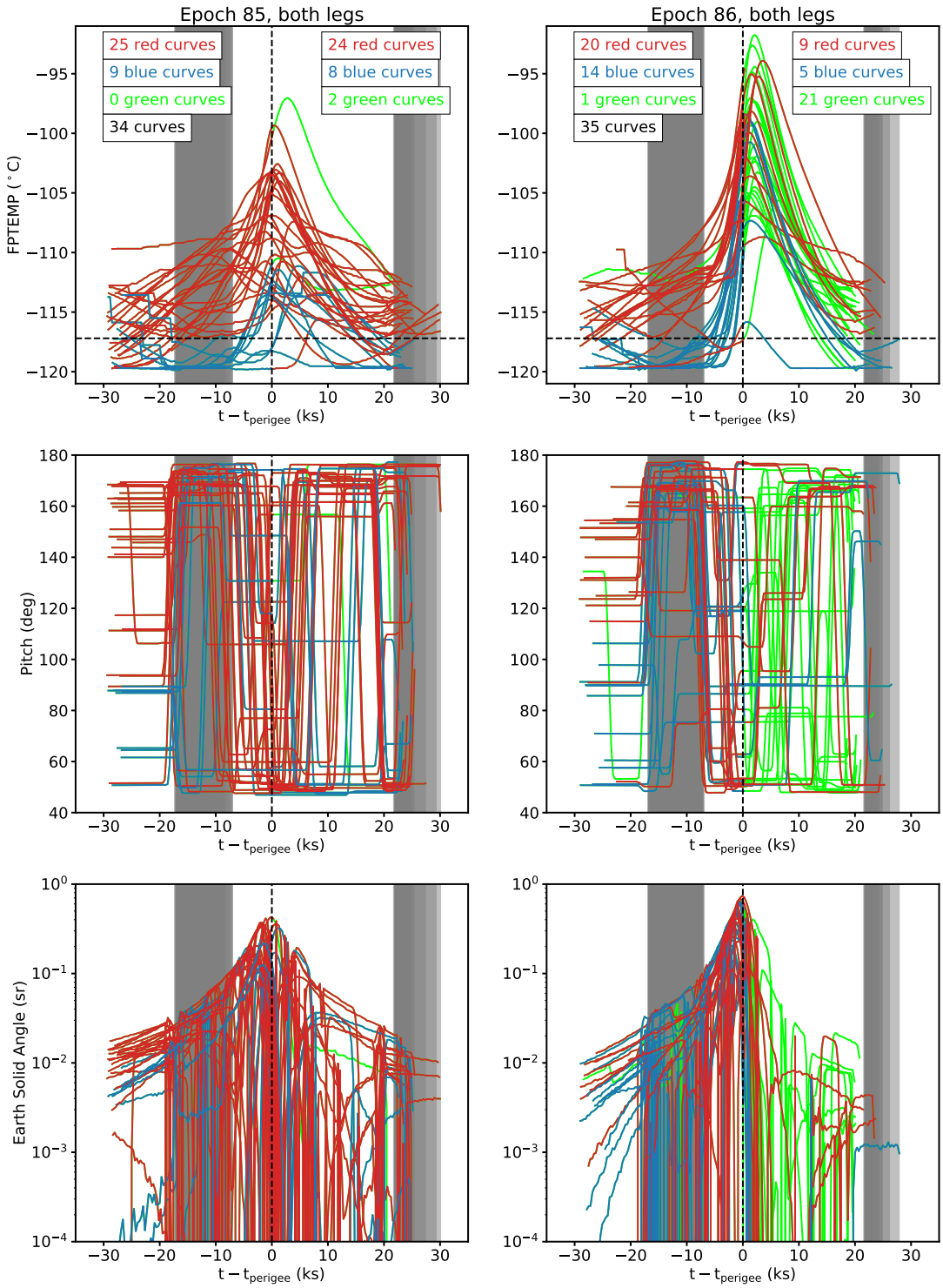

Figure 1: Curves showing the ACIS FP temperature (top row), pitch angle (middle row), and Earth solid angle (bottom row) vs. time, centered on the time of perigee, for every radzone in epochs 85 (left panels) and 86 (right panels). Blue curves indicate legs with "cold" ECS measurements where the FP temperature is less than -117.2 °C for at least 70% of the time, and red curves indicate legs with ECS measurements which are warmer. Green curves indicate legs without an ECS measurement. Gray shading indicates when ECS measurements occurred.

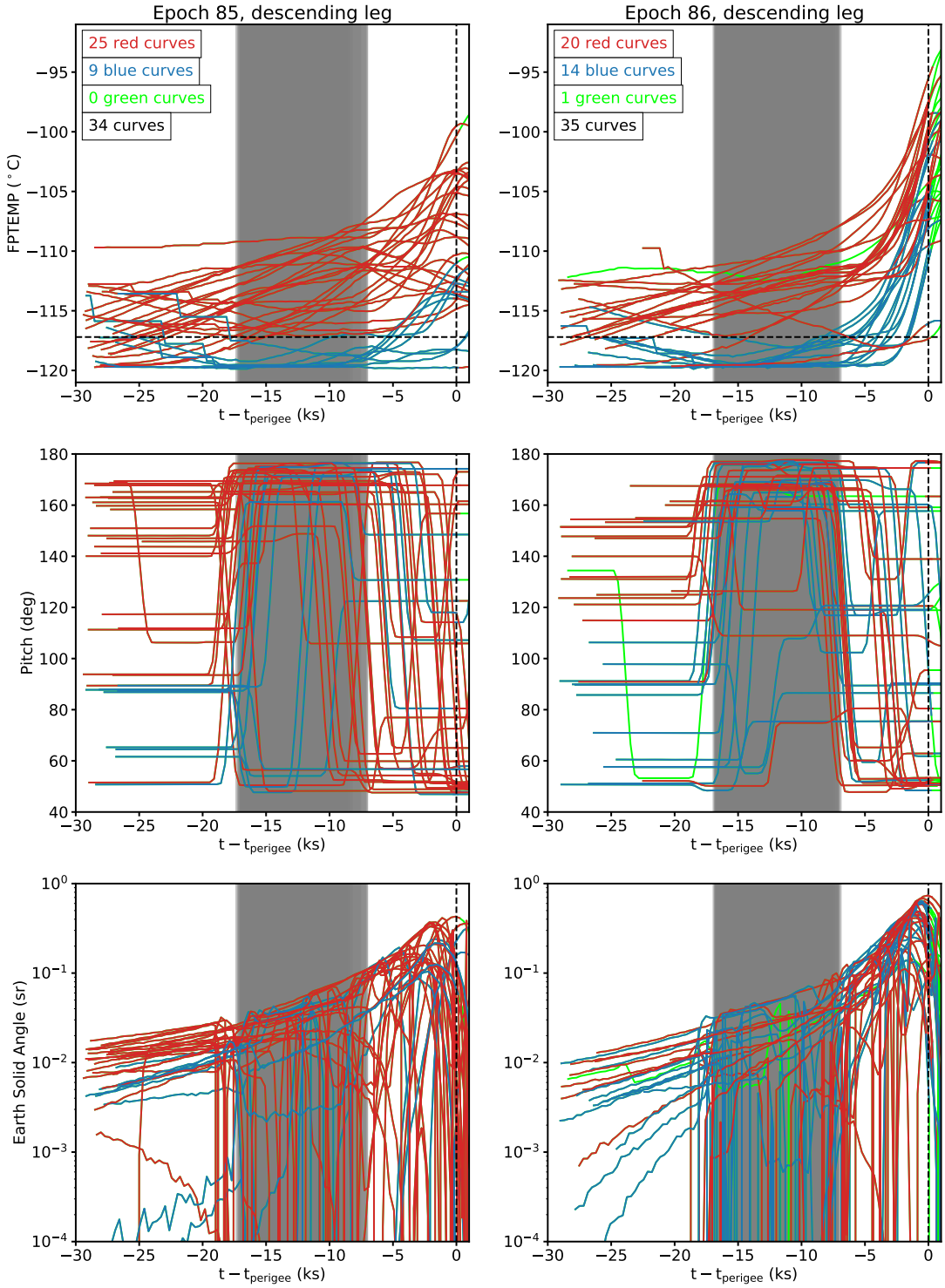

Figure 2: Same as Figure 1, but only showing the descending leg.

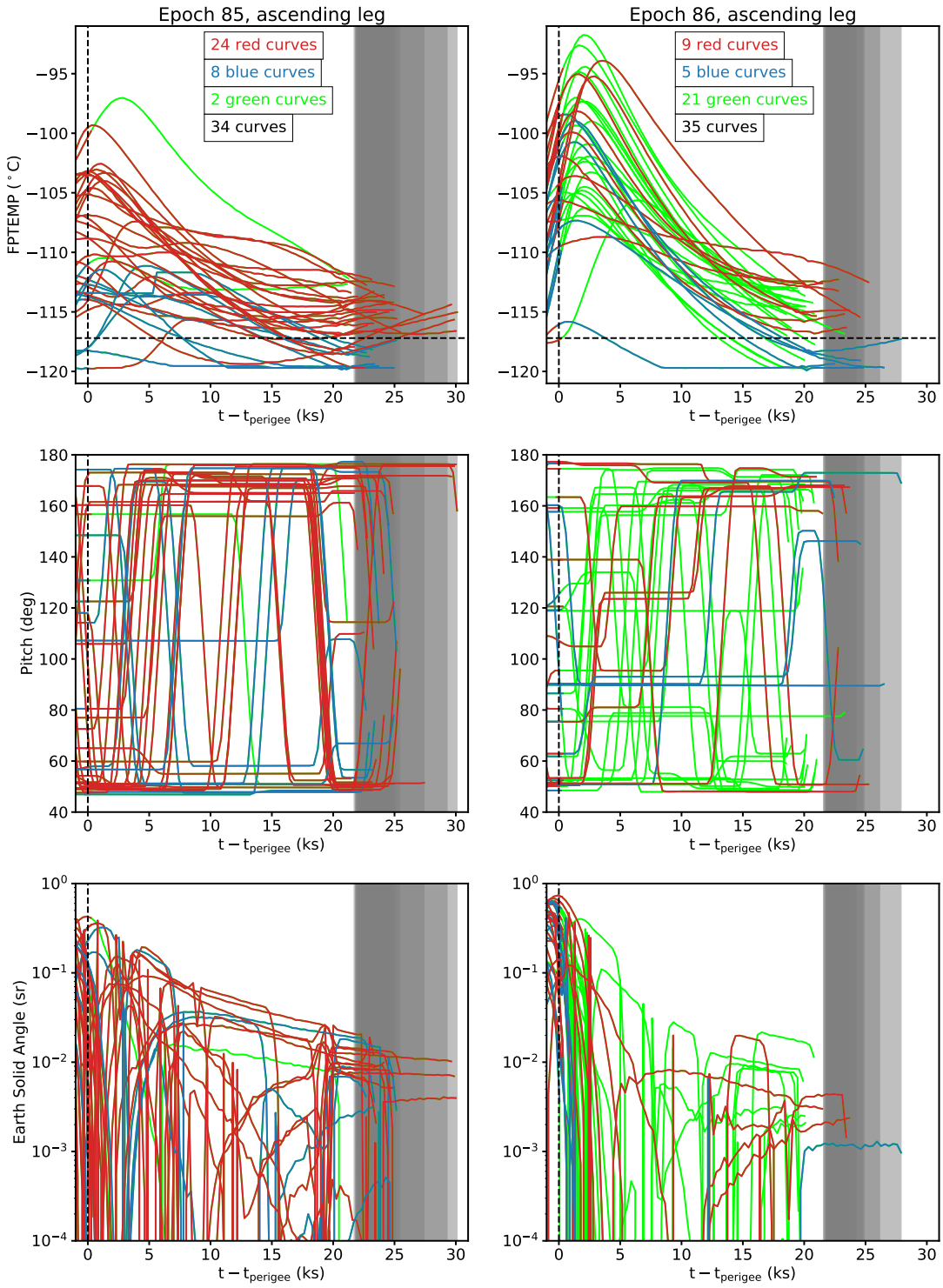

Figure 3: Same as Figure 1, but only showing the ascending leg.

and the attitude quaternion. ECS measurements are indicated by gray shading on either side of perigee. Needless to say, most of them overlap to some degree; they are only shown on the plots as a visual aid to show where the relevant FP temperatures for the purposes of this analysis are located.

The curves in each plot are split between the descending leg (left/negative of perigee) and the ascending leg (right/positive of perigee). The curves which are colored blue are those for which there is a "cold" ECS measurement on that leg, and those which are colored red are those for which there is a "hot" ECS measurement on that leg. Here, a curve is determined to be "cold" if the ACIS FP temperature is less than -117.2 °C for at least 70% of the length of the ECS measurement (excepting the bias). The green curves are those for which there is no ECS measurement on that leg, usually occurring on the ascending leg, where science observations begin immediately upon exiting the electron belts. The numbers of each curve are also labeled on the plots on either side of the perigee line. Figures 2 and 3 show the same information, but for either the descending or ascending legs only. The total number of radzones in each epoch is essentially the same: 34 in epoch 85 and 35 in epoch 86.

Several things are immediately apparent from these plots:

- There is a larger fraction of cold ECS measurements in epoch 86 than epoch 85, though the number of cold ECS measurements in both epochs is roughly the same, 17 vs. 19, respectively. There are far more hot ECS measurements in epoch 85 than in epoch 86: 49 vs. 29, respectively.

- In epoch 85, there were only 2 legs without ECS measurements. In epoch 86, there were 22 legs without ECS measurements. Most of these occur in the ascending leg. This accounts for the apparent discrepancy in the number of hot ECS measurements noted in the previous point.

- From the panels which show the pitch angle (middle rows), it can be seen that there are a substantial number of curves in the descending leg which have a pitch angle larger than 140 degrees in the observation before the ECS measurement, which implies that the ACIS FP will likely begin at a fairly hot temperature when the ECS measurement starts. The number of curves with a pitch angle larger than 140 degrees in epoch 85 is 17, whereas for epoch 86 it is 11. In the descending leg, nearly all of the blue curves have forward-Sun or near-normal-Sun pitches before the ECS measurement begins.

- From the panels which show the Earth solid angle (bottom rows), it can be seen that this quantity drops to zero shortly after perigee for all of the blue/cold curves, whereas most of the red/hot curves have some significant Earth solid angle after perigee. A large number of the green curves without ECS measurements appear to have significant Earth solid angle after perigee.

4 Summary

From the above analysis, we tentatively draw the following conclusions:

- The larger number and fraction of cold ECS measurements in the descending leg of epoch 86 vs. epoch 85 appears to be primarily due to the fact that epoch 85 contained a larger number of observations with tail-Sun pitch at the end of the science orbit than epoch 86.
- The larger fraction of cold ECS measurements in the ascending leg of epoch 86 vs. epoch 85 appears to be due to a combination of factors: a larger fraction of ECS measurements with smaller Earth solid angle, many of the ascending legs did not contain ECS measurements, most of which appear to have significant Earth solid angle, and lower pitch angles previous to the ECS measurements.

It appears that the recent turning off of the Zone 50 heater, which reduced the temperature of the ACA, has allowed more observations at the end of the science orbit at attitudes favorable to ACIS from a thermal perspective, which results in colder descending ECS measurements. Ascending ECS measurements are most likely to be cold when the Earth solid angle is small and the pitch angle prior to the measurement is not tail-Sun. Given other constraints on the spacecraft, these are not conditions that can always be met. More study is required to understand the relative impact of these two effects on the ACIS FP temperature for ascending leg ECS measurements.