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MEMORANDUM

Date: February 27, 2018
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To: ACIS Team
Subject: Estimation of the Thermal Expansion of the ACIS Collimator
Cc: Chandra Thermal Working Group
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1 Abstract

We present an approximate calculation of the thermal expansion of the ACIS colllimator, and show that it is small compared to the Chandra depth of focus.

2 Introduction

ACIS is attached to the Chandra spacecraft through a collimator. This is tapered, approximately 13 inches long, and made of one piece of titanium. By design, the end attached to the camera body is held at approximately $-60°$C, while the end attached to the ISIM is much warmer, around $-15°$C.

The camera body is instrumented with two temperature sensors, recorded in the MSIDs 1CBAT and 1CBBT. There is another temperature sensor, 1DACTBT, near the top of the collimator.

In 2017 it was observed that the readings of 1DACTBT had been trending upwards, and there is some risk of exceeding the yellow high limit for this quantity, which is set at $-5°$C. For reference, the red high limit is $0°$C. These limits were set somewhat arbitrarily, to give due notice if something started to change. The precise values are not protecting any particular piece of sensitive equipment.

The steps of the digitized readout of this MSID are fairly large, approximately $2.5°$C.

In order to support the idea of raising the high limits for this quantity, we undertake in this memo to estimate the thermal expansion of the collimator, and discuss the impact on the telescope focus. If, for example, the collimator top runs $10°$C warmer, would that result in a measureable change to the telescope focus?

3 Setup of the Problem

We will model the collimator as a titanium ruler. Distances in this problem are measured in two ways, one as usual (for example, wavelengths of light in vacuum), and the other using the markings on our ruler, which is subject to thermal expansion and shrinkage.

Let x represent distance along the ruler in real units, and s be distance as measured by the ruler. We then hope to derive how s changes as a function of temperature.

Relevant quantities to this problem include the coefficient of thermal expansion, CTE, *alpha*. This was measured by Hidnert (1943), who very conveniently measured the average value of the quantity over the range from −80 to +20°C, just the range of interest here. The value they quote is 8.3×10^{-6} C^{-1}, i.e. 8.3 parts per million per degree Centigrade. The paper is in the Journal of Research of the National Bureau of Standards, v30, p101. A copy can be found in the web folder containing this memo.

We will first calculate the change in size of the collimator between uniform temperature of zero C, and the nominal operation configuration, where the temperature runs from −60 to 0°C. We will then calculate the derivative of this quantity with respect to the temperature at the warm end of the collimator. Lastly, we will compare the expansion for a temperature change of 10°C to the measured depth of focus for the telescope and its errors.

4 The Nominal Configuration

Since thermal expansion is given as a fractional change per unit temperature, we can write

$$\frac{1}{s}\frac{ds}{dT} = \alpha,$$

where T is the local temperature of the metal. We will need to derive the temperature structure in the bar. If the thermal conductivity is roughly constant with temperature over the range of interest, it follows that the temperature is linear in the distance. If we set $x = 0$ at the warm end of the bar, it follows that

$$T(x) = T_0 - Cx$$

for some constant C. The value of this constant is related to the thermal conductivity of titanium, and the heat flux through the collimator. If $T = T_{min}$ at $x = x_{max}$, it follows that

$$C = \frac{T_0 - T_{min}}{x_{max}} = \frac{\Delta T}{x_{max}} \approx \frac{60 \text{ C}}{33 \text{ cm}} \approx 1.9 \text{ C cm}^{-1}$$

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Note that the value of C depends on the temperature difference along the collimator.

Therefore, $s(x)$ follows this equation:

$$\frac{ds}{dx} = \alpha s \frac{dT}{dx} \approx \alpha x \frac{dT}{dx} = \alpha C x,$$

where the small expansion approximation allows replacement of (non-differential) x for s on the right hand side.

Integrating, the length of the bar S is given by

$$S = \int_0^{x_{max}} \alpha C x \; dx = \frac{1}{2} \alpha C x_{max}^2.$$

But $C = \Delta T / x_{max}$, so $S = \frac{1}{2} \alpha x_{max} \Delta T$.

From this it is clear that

$$\frac{dS}{d\Delta T} = \frac{1}{2} \alpha x_{max} \approx 1.37 \; \mu\text{m C}^{-1}.$$

For example for a 10 degree change in the temperature difference between warm and cold ends, the collimator would expand or contract about 13.7 μm.

5 Comparison to Chandra Depth of Focus

As described by Beckerman and Johnson in a Chandra Calibration Memo TBR dated March 2000, a series of measurements were made at various focus adjustments, the blur computed, and the location of the best focus of the system was derived to be consistent with the original determination from Orbital Activation and Checkout (August 1999). In particular, they derive a best fit optimal focus $-25 \pm 35 \mu$m from the position measured in OAC. This memo is linked here:

`http://asc.harvard.edu/cal/Hrma/PlateFocus-2000-03-31.html`

Our derivation above gives a change to the focus of roughly a third of the error quoted for the best focus, for a collimator temperature change of 10 degrees C.

We therefore conclude this effect is not an issue.