LETG

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1. Ungainly Aging

Its not unusual for the aging process to cause things to sag and droop. We will not know how many *Chandra* years makes one human year until the mission ends, but hopefully its only about 3 or 4. There is no getting around it though: after 12 years in orbit *Chandra* is firmly in middle age.

The HRC-S was born a year or so before the *Chandra* launch, and its aging process began much earlier than the rest of the spacecraft. On the ground it was subjected to subassembly calibration and "burn in" of the microchannel plates at count rates of thousands to tens of thousands of counts per second. Aging in orbit occurs when subjected to the 1700 V or so of tension between top and bottom microchannel plates during observations. This voltage serves to amplify the charge liberated by X-ray photon interactions with the top microchannel plate surface and its photoelectric effect-enhancing CsI coating. The resulting electron cascade within the pores of the plates is the signal that is detected and enhanced by amplifiers connected to a fine grid of wires situated beneath the plates. The magnitude of the signal for a given X-ray photon is referred to as the "pulse height" and is a measure of the gain of the instrument.

After years of use and bombardment by the ambient particle background, the plates "age", losing some of their photoelectic efficiency. This occurs primarily through chemical migration in the bottom plate where all the charge comes from. The net result is likely to be gain droop. Part of the routine monitoring of the HRC calls for regular observations of designated calibration sources whose behaviour is fairly constant and, if not, hopefully reasonable well-understood. For the HRC-S, the hot DA white dwarf HZ43 is the standard effective area monitoring source. It is thought constant and is the brightest source in the sky over much of the LETG+HRC-S wavelength range, providing useful signal from 50–170 Å in exposure times of 20 ks or so. We observe it every year and look at the count rates as a function of wavelength and detector position, and examine the pulse height distributions of the X-ray events.

Since launch we have observed a slow secular decline in the LETG+HRC-S count rates from HZ43. This meant either the discovery of exciting new white dwarf physics in which HZ43 is cooling at rates orders of magnitude faster than theory predicts, with startling implications for both astrophysics and physics in general. . . or a change in detector performance. We discovered the QE decline was accompanied by a slow decline in the event pulse height distributions—a sure sign of gain droop. The gain change itself did not matter too much, other than making the background filter Brad Wargelin had painstakingly developed based on X-ray pulse heights entertainingly more complex to implement. The QE decline was slow—just a bit more than 1% per year—and so practically inconsequential considering the absolute precision of the LETG+HRC-S effective area of about 15%. After accumulating a decade's worth of data we thought we had the QE decline well-characterized and included the effect in the *Chandra* calibration database by means of time-stamped detector quantum efficiency (QE) files: when generating effective areas for an observation in CIAO, the appropriate QE file for the time of the observation is incorporated automatically.

Perhaps unlike human aging, for detector aging grey is good. We want to see grey changes—changes that are essentially uniform with wavelength so that complex secular energy-dependent calibration models do not have to be constructed. The HRC-S QE decline looked grey, though at one time one of us who shall remain nameless (JJD) foolishly lost his house and all its contents on a bet that it was non-grey. It did in fact look grey until about two or so years ago, when we noticed that the

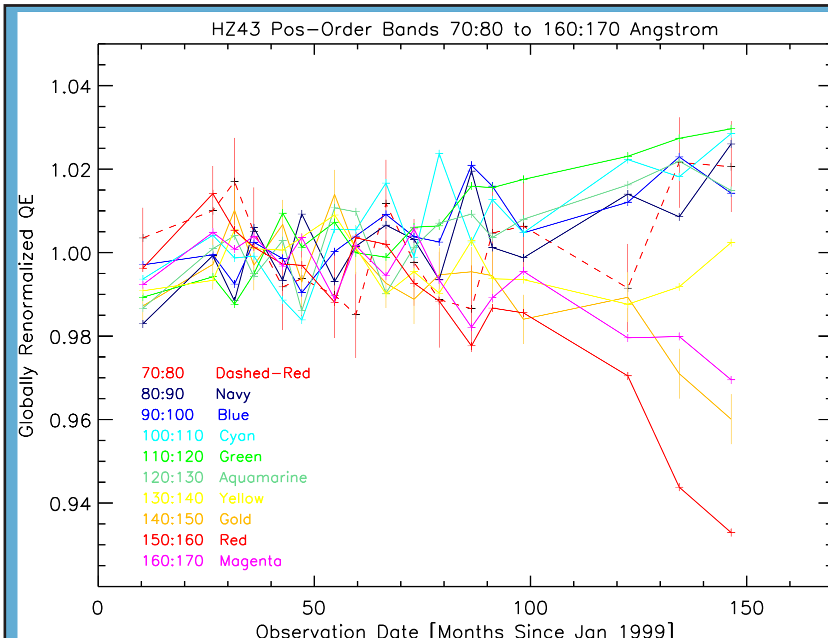

Fig. 1 - Gain droop on the HRC-S leads to loss of valid events in the longest wavelength channels. This mid-analysis figure made by "no gain without pain" expert Brad Wargelin shows trends in count rate for HZ43 in different wavelength regions. Note the relative decline at later times in the gold, red and magenta curves for $\lambda > 140$ Å.

longer wavelengths of the latest observed HZ43 spectra seemed slightly depressed compared with earlier trends. To define the trend, more data were needed (Fig. 1), and the non-grey QE drop is now quite obvious.

Why is the QE decline now non-grey? The bombardment by ambient particles produces photoelectrons and detectable signal, just as X-ray events do. The pulse height distribution for particles is quite different to that of X-ray photon events, and is essentially flat over the pulse height range of the former. However, most of the particle events have low pulse heights, and these events cause the full pulse height distribution to rise strongly at lower values. To avoid wasting valuable telemetry on these particle events, they are filtered out onboard. Gain droop though has meant that the pulse heights of the lowest energy photon events are now beginning to merge with the background signal and some some are not being telemetered. In order to remedy this, we need to raise the detector gain—a face lift for the sagging. The gain can be increased by raising the high voltage between the front and rear plates, enhancing the electron cascade. It is not a trivial exercise however: taken too far, the high voltage could result in breakdown and arcing, potentially destroying the instrument. How did it turn out? See the HRC article on page 10 to find out.

2. Learning Curve

The LETG+HRC-S effective area curve relies, more than any of *Chandra*'s other instruments, on in-flight calibration using cosmic X-ray sources. *Chandra* was largely calibrated on the ground over many weeks through an extensive military-stye operation directed by Generals Weisskopf and Tananbaum at the MSFC X-ray Calibration Facility (XRCF). The best calibration data came from electron impact point sources (EIPS) in which an electron beam is accelerated onto an anode with sufficiently high voltage to excite "K-shell" transitions through removal of 1 s electrons. The X-ray spectrum of such a source usually has a nice bright K-line on top of a weaker continuum—a reasonable approximation to a monochromatic X-ray source (though the full X-ray spectral energy distribution generally had to be taken into account in analysis). The problem is that the energy spacing of K lines is rather sparse—C K at 0.28 keV, B at 0.18, Be at 0.11—and the HRC-S QE was not necessarily so slowly varying with energy that we could just join up the dots between the sparse measurements with straight lines.

XRCF was equipped with good monochromators that could be operated with continuum sources to select out nearly monochromatic X-rays of the desired energy. But the refections inside the monochromators tended to produce an X-ray beam that was not nearly as uniform as the beam from the EIPS alone. The calibration method, in essence, was to compare the detected signal in *Chandra*'s instruments with beam flux measured both at the telescope aperture and at some distance up-beam. The beam uniformity mattered because these beam measurements were spot measurements made by 4 flow proportional counters at the mirror entrance and one up-beam—again a problem of how to join the dots between the sparse measurements. In addition to these difficulties, the final in-flight high voltage settings of the HRC-S were optimized to slightly different values to those employed in ground calibration leading to expectations of different quantum efficiency between ground and flight conditions.

In Newsletter 13, I described some of the initial in-flight calibration of the LETGS based on hot white dwarf spectra (see Pease et al. (2000) for a more detailed description). *Chandra*'s low energy monitoring "standard candle" is the hot white dwarf HZ43. With a temperature of about 50,000 K, it is sufficiently hot to produce useful signal in the LETG+HRC-S down to about 50 Å or so. But as a single star, its surface gravity relied on spectral modelling in the UV-optical range. White dwarf X-ray fluxes are very sensitive to both the assumed effective temperature, and the surface gravity, and so a white dwarf with a better known mass was enlisted to help: Sirius B. The initial LETGS low energy in-flight calibration was, then, based on the spectra of HZ43 and Sirius B. Using the best models and stellar parameters of the day they did not quite agree where they overlapped though, and we had to do some guesswork to merge the two spectra and obtain what we thought was the best "average" effective area curve.

Subsequent years saw some improvements in the atmospheric models and in understanding the stellar fundamental parameters, and defects in the effective area model became apparent. The shorter wavelengths were re-calibrated using blazar spectra, taking advantage of overlap and cross-calibration with the HETG and ACIS-S detector—see Newsletters 16 and 17. Some foundations for a re-calibration at longer wavelengths using HZ43, Sirius B, and even assuming the spectrum of the isolated neutron star RXJ 1856 − 3754 might be a pure blackbody, were made by colleagues at LETG PI institutes MPE and SRON by Bauermann et al. (2006) and Kaastra et al. (2009). PhD student Benedikt Menz and long-time colleague Vadim Burwitz pioneered including another hot white dwarf, GD153, into the mix. With an effective temperature of 39000 K the latter bridges the effective temperature gap between HZ43 and Sirius B.

One result of all this work we took advantage of here was a growing confidence in parameters for HZ43 and that its spectrum was well-represented by pure hydrogen atmospheric models. We found that by co-adding 10 years' worth of HZ43 calibration data obtained since launch enabled us to obtain useful signal down to the C K edge, meeting up with our earlier blazar calibration. This offered a promising approach: the much cooler Sirius B X-ray model fluxes al-

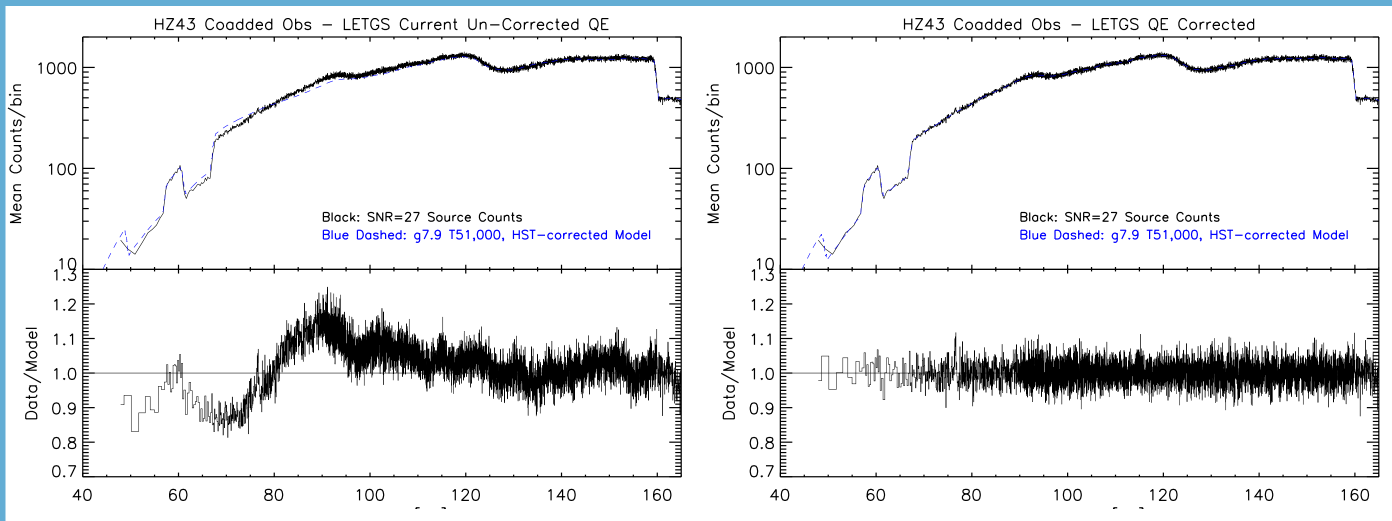

Fig. 2 - The before and after test of the new HRC-S QE model based on 10 years of accumulated HZ43 calibration data.

ways seemed worryingly sensitive to fine details of the model atmosphere calculations and a calibration based on a single reference source—HZ43—held immense Occam's razor-like appeal. IT Specialist Nick Durham carefully accounted for the secular HRC-S QE decline, and reprocessed the data what must have seemed to him like several hundred times to account for small ~1% level tweaks and perfections in things like higher order contributions, extraction efficiencies and HRC deadtime correction uncertainties. Data showing the non-grey gain sag were carefully excluded. The most up-to-date non-LTE pure hydrogen atmospheres available were computed by Thomas Rauch at the Eberhard Karls Universität Tübingen. Curves, bumps and wiggles in the data/model residuals were liposuctioned out and the QE smoothed out and stitched back together. The before and after comparison of residuals for HZ43 are illustrated in Fig. 2. The largest correction is the smoothing out of the S-shaped chicane in the residuals in the 60–90 Å region—a legacy from the earlier Sirius B-HZ43 compromise.

So, now that the HRC-S gain has been fixed, secular decline in QE is incorporated and it has been re-calibrated throughout its working range—covering a huge factor of 140 in energy—are we finished? Well, the problem is that the high voltage change to the detector will likely have an effect on the QE: once the optimum new settings have been established we will need to start over again. . .

JJD thanks Ralph Kraft and the LETG team for useful comments and discussion.

References

Beuermann, K., Burwitz, V., & Rauch, T. (2006). A&A 458: 541.
Kaastra, J. S., Lanz, T., Hubeny, I., & Paerels, F. B. S. (2009) A&A 497: 311
Pease, D. O., Drake, J. J., Johnson, C. O., et al. (2000). Proc. SPIE 4012:700.