LETG Update

Jeremy Drake, for the LETG team

“If it ain’t broke...

don’t fix it.” Best said in a Northern English accent by a mature gentleman in a tweed jacket and a flat cap, holding a pipe by the bowl end and motioning the stem in the air for particular emphasis. A gentle poking gesture in the direction of the keen but naive youngster on the receiving end is also particularly effective. Yorkshire or Lancashire accents—hopefully not risking offence by conflating those two mortally-opposed bastions—sound best for the passing along of time-honored wisdom, giving the impression that wisdom must slowly seep out of other areas of the country, leading to foolish meddling with success in the Midlands, purely cosmetic “improvements” in Wessex, and needless “upgrades” in the Home Counties.

What a splendidly sensible maxim to live by though. And so, there we were, not fixing things that weren’t broken, but steadily going through our secret list of unsolved calibration problems—see *Newsletter 24* page 26 for a description of that sacred process—when the LETG phone, in its prime location on the desk, with the big red light on it, started to flash. It is our secure direct line to the *Chandra* Helpdesk, immune to the inevitable attempts at interference and hacking by hostile agents of foreign space missions. Cutting out the opaque cryptomission jargon, the gist of the communication was that someone had reported that our wavelengths were a little bit broken.

The LETG is much like a traditional transmission grating, where the diffraction pattern comprises a 0^{th} order, corresponding to light passing straight through, and symmetric diffraction into higher orders either side, corresponding to “positive” and “negative” dispersion directions along the dispersion axis. In order to wring the most out of grating observations, both HETG and LETG, the positive and negative orders are either added together to combine the signal, or else analyzed together by simultaneous parameter estimation within a model fitting engine, such as XSPEC or *Sherpa*. The requirement for this of course is that the dispersion relation for + and − sides be identical, or at least to within the precision with which it is possible to measure it. This is quite easy if the detector is nicely physically pixelated, like a CCD. Diffracted photon positions can be assigned to particular pixels (or groups of pixels, nothing being quite so simple in the X-ray world) in which they were detected and that have precisely known positions in space.

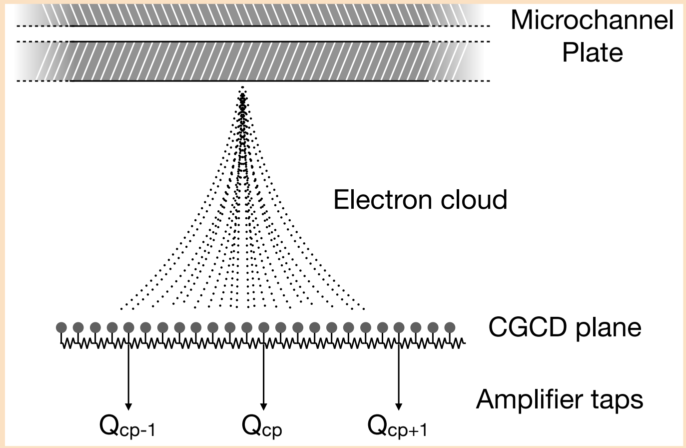

Figure 1: Schematic of the determination of photon event positions in the HRC detector. It is an analog instrument, and event positions are determined from the signals Q_{cp-1}, Q_{cp}, Q_{cp+1} from the nearest amplifier “taps” to a charge cloud from the bottom of the microchannel plate stack.

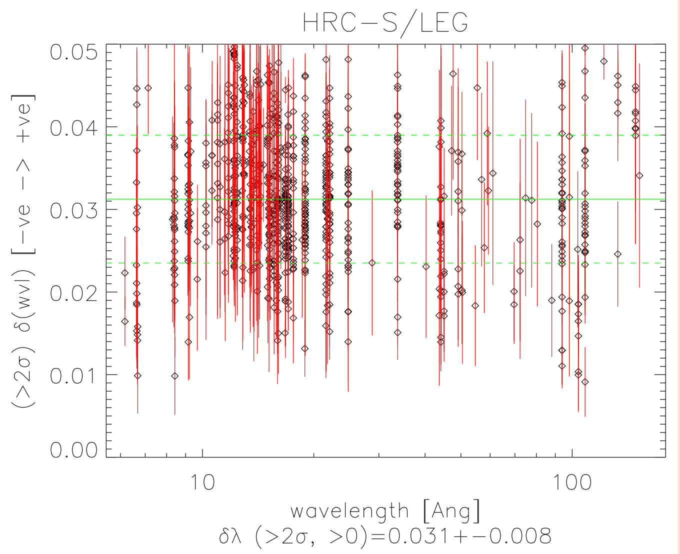

Figure 2: Measured shifts between lines seen in the − and + orders for a variety of strong lines in numerous LETG+HRC-S observations of coronal sources. Only lines detected at >2σ and displaying a positive line shift are shown here, as diamonds with red vertical lines signifying ±1σ error bars. The average line shift is represented by the horizontal green line, and ±1σ width of the distribution of line shifts is shown as the horizontal dashed green lines. Figure courtesy of Vinay Kashyap.

The HRC-S detector does not have pixels though. Instead, the position of a photon event is determined from a charge cloud initiated by the photoelectric effect and boosted by a high voltage-fueled electron cascade within the capillaries of the microchannel plates. The charge cloud exiting the bottom of the plates—20 million or so electrons, or about one each for every Australian—is detected by a square grid of conductors connected to amplifiers, with the position being determined by the relative amplitudes of the signals seen in the nearest three amplifier “taps” in each orthogonal axis. Some charge spills outside of the three taps, which spoils the position determination algorithm; the resulting map of raw event positions has regular tap-spaced gaps, a bit like my dad’s wallpaper. The position spoiling depends on the shape of the charge cloud and, unlike my dad’s wallpaper, can be corrected for empirically: hence the arcane term "degap correction" that is applied to close up the gaps.

That is not the end of the story though. *Chandra*'s fine point spread function demands sub-arcsecond precision in photon positions, of which the system is capable on paper. But it is an analog system and subject to little distortions and ripples, reminiscent of my dad's wallpaper, that can perturb the position determination. Back in Newsletters *11* and *12*, I described empirical corrections to the ripples along the dispersion axis using bright emission lines with accurately-known wavelengths. A source is typically dithered in a Lissajous pattern about 2 mm square, and the trails of bright lines on the detector nicely mapped out the distortions. Several years later, in the aimpoint region of the detector this was replaced by a more comprehensive job that utilized raster scans of point sources originally undertaken to monitor the detector point source imaging capability. The wallpaper was painted over: job done.

Which brings me back to the flashing red LETG phone. There are many suitable metaphors to describe X-ray mission calibration—one topic of *Newsletter 24*'s article. Perhaps the least unpleasant is the analogy of trying to squash a balloon between your hands: no matter how carefully you position your fingers or hold the balloon, as you squash down one or more pieces of it will blister through an inevitably unguarded fissure and pop out at you. Like a macroscopic perversion of Heisenberg's Uncertainty Principle, something always seems to get in the way of calibrating multiple aspects of the system at once without repercussions in one of more of them. We had squashed down the balloon of photon position distortions, but had not noticed the little blister protruding from behind. By fixing the problem, we had also broken something.

The problem was that it was not possible to get truly continuous information on the photon position errors. At some point, a bit like my dad's wallpaper, pasting together of corrections for different detector regions had to be done. Unappreciated at the time, this process apparently introduced about a 0.3″ systematic position offset in the middle of the detector compared with regions further out, leading to small wavelength mismatches in + and − orders. Chief HRC calibration scientist and crack astrostastician, Vinay Kashyap, worked out the magnitude of the effect, illustrated in Figure 2. Vinay also concocted a correction for the problem in the form of a revised degap map that will be implemented and released by the time this Newsletter reaches your hands. The wallpaper has been repainted then. Subtle hints of the original pattern might still be discerned through the paint in a good light, just like at home. It is difficult to fix it further—more coats of paint in the form of extensive new calibration data would be needed. Besides, it is not really broken now.

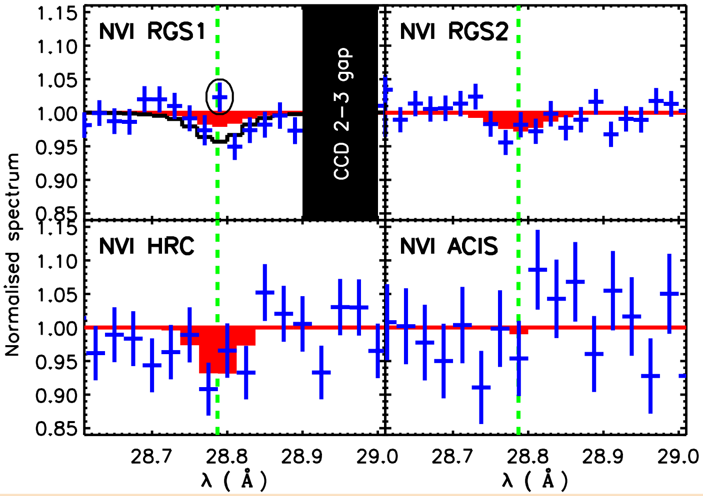

Figure 3: Normalized data (blue crosses) and best-fit models (solid red lines) of the transition temperature N VI λ28.788 line for RGS1 and RGS2 (upper panels), LETG/HRC-S (lower left), and LETG/ACIS-S (lower right). From Nevalainen et al. (2017).

Galactic Font of Wisdom

Though not from Lancashire or Yorkshire, Lyman Spitzer still had somewhat of a reputation for wisdom. In 1956, his paper "On a possible interstellar Galactic corona" proposed that neutral gas clouds far from the galactic plane were supported by a "rarefied, high-temperature gas" (Spitzer 1956). This idea eventually evolved into the "Galactic Fountain" of Shapiro & Field (1976), in which gas in the interstellar medium heated to a million degrees by supernova explosions expands vertically above the galactic plane, cools, and subsequently rains back down again. Observing this process provides insights into galactic evolution and the lifecycle of gas in galaxies.

The model predicts that there should, then, be infalling gas at "transition temperatures"—temperatures similar to that of the solar transition region, or 10^5 K or so. Such gas has in fact been detected in the far ultraviolet in ions such as O VI, N V, C IV, and Si IV (e.g., Wakker et al. 2012). While the 10^6 K coronal gas has been detected in X-rays, the transition temperature gas has not.

Nevalainen et al. (2017) have recently righted this wrong, by coadding about 3 million seconds of high-resolution grating observations of the blazar PKS 2155−304 obtained by the *Chandra* LETG and the *XMM-Newton* RGS. The blazar acts as a convenient backlight to shine through the galactic corona. And there it was, transition temperature gas revealed by the absorption lines of C VI, N VI (Figure 3), O V and O VI. Combining the X-ray data with FUV detections indicated that the gas is not photoionized. Instead, the authors found the oxygen line strengths to be in agreement with a model in which the observed ions originate in isobarically cooling gas with solar abundances and a temperature of log T(K) ~ 5.2 and not far from collisional ionization equilibrium; all consistent with general expectations from the galactic fountain scheme.

Nothing broken worth fixing there then, either. ■

JJD thanks the LETG team for useful comments, information and discussion.

References

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